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Volume I

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Prepared For
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March 1976

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16. ABSTRACT The report gives results of an examination of technical and environmental incentives for increased electrification in stationary use sectors. It compares the impacts which result from the production and consumption of equivalent quantities of natural gas, fuel oil, and electricity. It also examines several alternative methods of producing each end-use fuel and considers technical and economic barriers to increased electrification. It concludes that incentives for increased electrification are associated with the potential of this technique to reduce fossil fuel demands per se since direct consumption of fossil fuels appears to be more attractive from an energy efficiency and an environmental impact viewpoint. Most of the natural gas and distillate fuel oil consumed in the U.S. is in the residential, commercial, and industrial sectors. Currently experienced shortages of these clean premium fuels are providing incentives for the development of new energy sources for these markets. Among apparent alternatives are increased exploration for new sources of oil and gas, and production of clean synthetic fuels from the more abundant (but less environmentally attractive) fossil fuels such as coal or oil shale. Increased use of electrical energy is another option for satisfying future stationary sector energy demands.

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VOLUME I

by

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1.0 INTRODUCTION

A great majority of the natural gas and distillate fuel oil consumed in this country is utilized in the residential, commercial and industrial sectors. Limitations currently being experienced in the availability of these clean premium fuels have led (or threaten to lead) to calls for reduced residential usage, to slowdowns in business expansion and home construction and to increased reliance upon more abundant "dirty" fuels (i.e., residual fuel oil and coal) by industrial energy users. This shortage of premium fuels has also resulted in an increasing emphasis on the development of technologies which are capable of producing clean fuels from abundantly available oil shale and high-sulfur coal. Oil shale processing, coal liquefaction and coal gasification are among the technologies which are currently under development which could ultimately help to satisfy future needs for clean fossil fuels.

An alternative to trying to satisfy an ever-increasing demand for gas and distillate oil is to shift that demand to another clean energy source; namely, electricity. An environmentally attractive arrangement can be envisioned in which electricity is generated in large central power stations, remote from the user, which burn abundant dirty fuels and employ suitable emission control technologies. Electricity would then be used as a clean fuel in homes, businesses and industries in place of gas and distillate oil. This study was intended to define the potential benefits that might result from the increased use of electrical energy as an alternative to the combustion of oil and gas by stationary end users.

Overall effort during this study was divided into eight separate subtask areas. Each of these is described briefly below.

Subtask 1 - Fuel Usage Assessment

Published surveys and projections were utilized to identify and predict major end users of raw fossil fuels in the stationary sectors at the present time and in the years 1985 and 2000. The raw fuels considered were natural gas, fuel oil, and coal. End uses within the residential, commercial and industrial sectors were broken down in sufficient detail to permit an assessment of the degree to which electricity could be substituted for fossil fuels. The results of this fuel usage assessment subtask are discussed in Section 3.0.

Subtask 2 - Definition of Alternatives

For each major end use determined in the energy demand survey, alternative fuel supply scenarios were identified which were capable of producing the needed energy in its desired end use form. As part of this subtask, specific items of electrical equipment which could be installed in stationary sectors in place of existing fossil fuel-fired equipment were defined. The results of this subtask are described in Section 4.0.

Subtask 3 - Evaluation of Energy Use Efficiency

After all significant fuel extraction, transportation, processing, distribution, and end use options were identified, the energy efficiency of each unit operation or module was defined. Then based upon the efficiencies of these individual process units, the ultimate end use efficiency at the point of energy resource consumption was estimated and compared for each significant fuel supply option. Alternative routes for satisfying each end use were ranked according to overall efficiency, with particular attention being paid to those end uses in the stationary sectors for which electrical alternatives exist. The results of this subtask are discussed in Section 5.0.

Subtask 4 - Evaluation of Total Environmental Impacts

The environmental impacts of each significant fuel extraction, transportation, processing, distribution, and end use module defined in the previous subtask were estimated. Based upon these individual module impact calculations, overall energy supply scenario impacts were determined. The results of this assessment subtask are discussed in Section 5.0.

Subtask 5 - Assessment of the Impact of Electrical Equipment Substitution on Ambient Air Quality

Ambient air pollutant concentration models were used to estimate the ambient air impact of converting fossil fuel-fired equipment in the stationary sectors to equivalent electrical equipment. The Air Quality Control Region which includes the Chicago, Illinois metropolitan area was used for this analysis. The results of this subtask are summarized in Section 6.0.

Subtask 6 - Projection of the Maximum Rate of Application of Electrical Equipment

The maximum rate at which electrical equipment could be installed in the stationary sectors between the present and the years 1985 and 2000 was estimated in this subtask. This effort included not only an assessment of the rate at which new electrical equipment could be manufactured and installed but also a consideration of the maximum rate at which new power plants could be constructed to meet the increased demand for electrical energy. These results are discussed in Section 7.0.

Subtask 7 - Definition of Equipment Costs

Estimates of present day installed capital and operating costs were prepared for each of the alternative equipment items designated in subtask 2. Cost estimates for alternative end use equipment items are compared in Section 8.0.

Subtask 8 - Discussion of Conclusions and Recommendations for Future Work

Conclusions which were generated based upon the results of the seven subtask items just described are presented in Section 2.0. Additional work which should be conducted to enable more firm conclusions to be made regarding the potential for the application of electrical equipment in the residential, commercial, and industrial sectors is also discussed in that section.

2.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations resulting from the accomplishment of the first seven subtasks described in the introduction are presented in this section. The specific conclusions resulting from each subtask are discussed first and then the general recommendations and the recommendations for future work are presented.

2.1 Conclusions

In summary, the oil and gas shortage and the threat of a new embargo provide clear incentives for further examination of the degree to which substitution of electricity (from coal-fired power plants) for oil and gas usage in stationary end use sectors can be implemented. Electrical substitution does offer the potential for significant future reductions in the amount of natural gas and distillate fuel oil consumed in the residential, commercial, and industrial sectors. The hardware and technology necessary for complete substitution of electrical energy for fossil fuels in the residential and commercial sectors and for limited substitution in the industrial sectors has already been developed. However, oil and gas can generally be produced more efficiently than electricity and with less environmental impact. At present cost levels fossil fuel consumption is definitely the cheaper alternative for the consumers.

Various institutional constraints would probably combine to make substantial electrical substitution a long-term program. This approach would avoid problems associated with the demonstration of the technology necessary to produce synthetic fuels from coal however.

Ignoring economics, the results of this study indicate that using coal to produce synthetic gas and liquid fuels to meet stationary sector end use requirements is preferable, in many cases, from both an efficiency and an environmental viewpoint, to using coal to generate electricity which could be used to satisfy the same end use requirements.

The specific conclusions of each subtask which result in the overall conclusions summarized above are discussed in the following subsections.

2.1.1 Subtask 1 - Fuel Usage Assessment

The results of the fuel usage assessment, which are discussed in detail in Section 3.0, show that the residential and commercial sectors are the two stationary end use sectors in which the potential for conversion from fossil fuels to electricity is greatest. Convertible fossil fuel end uses in these two sectors accounted for 88% of the total convertible fossil fuel end uses for the three stationary sectors considered. Essentially all of the fossil fuel end uses in these two sectors are convertible to electricity with the exception of fossil fuels used for feedstocks in the commercial sector.

A variety of factors ranging from the large number of distinct energy uses in this sector to the lack of availability of electrical hardware for many end uses within the industrial sector combine to make only 9% of the fossil fuel energy consumption in the industrial sector convertible to electricity.

Conversion of all switchable stationary end uses in the residential, commercial, and industrial sectors from fossil fuels to electricity in 1972 would have reduced consumption of fossil fuels in those sectors by approximately 15 x 10^{15} Btu. Maximum conversions by 1985 and 2000 would represent reductions of 20 x 10^{15} Btu and 25 x 10^{15} Btu respectively. If the additional electrical energy required for these conversions were provided by new coal-fired or nuclear power plants, these reductions in end use consumption of fossil fuels would represent a real reduction in our national consumption of natural gas and distillate fuel oil.

The potential reduction in consumption of these clean premium fuels would be the equivalent of 9 x 10^6 barrels of oil per day in 1985 and 12 x 10^6 barrels of oil per day in 2000. Conversion of all switchable fossil fuel end uses in 1972 would have represented a reduction in oil and gas consumption equivalent to approximately 7 x 10^6 barrels of oil a day or approximately our present level of oil imports. While there are numerous institutional barriers to complete immediate conversion to electricity (these are considered in Section 7.0 of this report) this potential savings in oil imports is significant in light of our expressed national goal of an immediate reduction in oil imports of 1 x 10^6 barrels per day and our long term national goal of eliminating oil imports entirely.

2.1.2 Subtask 2 - Definition of Alternatives

For each major end use identified in the fuel usage assessment subtask, specific items of electrical equipment which could be installed in the residential, commercial, and industrial sectors in place of existing fossil fuel-fired equipment were defined. Alternate fuel supply scenarios were identified for producing the needed energy in the desired end use forms. The definition of alternatives is presented in detail in Section 4.0.

The results of this subtask showed that 99% of the fossil fuel consumed in the residential sector was used for four end uses - space heating, water heating, cooking, and clothes drying. Suitable electric equipment for replacement of fossil fuel-fired equipment was identified for each of these end uses. The electrical equipment identified was substantially more efficient than the comparable fossil fuel equipment for each of the end uses.

Discounting fossil fuels used as feedstocks, 99% of the fossil fuel consumed in the commercial sector was also represented by four end uses - space heating, water heating, cooking, and air conditioning. Here again, suitable electrical equipment for replacement of fossil fuel-fired equipment was identified for each of the four end uses. As was the case with the residential sector, the electrical equipment identified was in all cases more efficient than the fossil fuel-fired counterparts.

Approximately 9% of the fossil fuel consumed in the industrial sector was used for end uses which were determined to be convertible. The balance was used in nonconvertible areas such as process stream, feedstock, and electrical generating, or for direct heat uses for which no suitable substitute electric equipment existed (cement kilns, petroleum stills, etc). Because of this the industrial sector accounted for only about 12% of the total convertible fossil fuel energy in the residential, commercial, and industrial sectors. The electric equipment identified for conversion consisted mainly of electric furnaces and ovens used in the primary metal, chemical, food processing, stone, clay, and glass industries. As was the case in the residential and commercial sectors, all industrial electric end use equipment identified was substantially more efficient than the comparable fossil fuel-fired equipment it was designed to replace.

Twelve different sources of the three end use energy forms (electricity, distillate fuel oil, and gas) were identified. Twelve fuel supply scenarios were prepared so that the overall efficiencies and environmental impacts associated with alternative methods of supplying energy to convertible end uses in the residential, commercial, and industrial sectors could be compared. In order to prepare these scenarios, all significant fuel extraction, transportation, processing, distribution and end use operations were defined.

2.1.3 Subtasks 3 and 4 - Evaluation of Energy Use Efficiency and Total Environmental Impacts

In the fuel supply and energy use scenario efficiency evaluations and environmental assessments, which are discussed in detail in Section 5.0, the efficiencies and environmental impacts of each of the significant individual steps in the fuel supply and end use scenarios were combined and the ultimate end use efficiencies and environmental impacts were estimated and compared. The twelve fuel supply scenarios were ranked according to the overall efficiency of extraction, transportation, and processing/conversion. These efficiencies ranged from 94% for the production of distillate fuel oil from crude oil to 28% for the production of electricity from physically cleaned coal.

As a result of the fuel supply scenario evaluations, it was shown that for each of the scenarios considered fossil fuels were produced more efficiently than electricity. This was due primarily to the low thermal efficiency of the electrical power generation step. Fossil fuel supply scenarios were also shown to be generally more attractive than electricity supply scenarios from an environmental point of view. Gross emissions of airborne pollutants from fossil fuel production facilities, for example, were almost always quantitatively less than those produced as a result of the generation of an equivalent quantity of electrical energy.

The end use scenario evaluation showed that because electrical end use equipment is substantially more efficient than comparable fossil fuel-fired end use equipment, the overall end use efficiencies for fossil fuels and electricity are very close, although in most cases fossil fuels maintained a slight edge. For example, the generation of high btu gas from coal had an overall fuel supply scenario efficiency of 66% whereas the electricity from coal supply scenario had an overall efficiency of 34%. When the efficiencies of 60% and 100% for gas space heaters and electrical resistance space heaters are factored in, the overall space heating end use efficiencies become 40% for space heating with high btu gas from coal and 34% for space heating with electricity from coal. If an electrical heat pump is used, the efficiency for electric space heating can be as high as 68% due to the high efficiencies of heat pumps which can be twice as efficient as resistance heaters. However, this end use efficiency difference is still not sufficient to overcome the fact that power plants emit substantially more air, water, and solid pollutants than the combination of fossil fuel processing/conversion plants and fossil fuel end use equipment.

2.1.4 Subtask 5 - Assessment of the Impact of Electrical Substitution on Ambient Air Quality

Although gross air emissions from electrical end use scenarios are typically greater than those generated by fossil fuel end use scenarios, increased electrification of stationary sector end uses in future years can be accomplished without significant degradation of ambient air quality. As can be seen from the results of the ambient air modeling of the Chicago Air Quality Control Region (AQCR), discussed in Section 6.0, intensive electricity usage in the residential, commercial, and industrial stationary energy end use sectors improves the rural air quality as far as particulates, hydrocarbons, and CO are concerned, does not change SO_2 levels, and slightly increases NO_x levels (9-15%). The urban air quality is improved for all five criteria pollutants (SO_2, NO_x, hydrocarbons, particulates, and CO) up to as much as 17% for SO_2. This SO_2 concentration reduction is due primarily to the conversion of coal usage in the residential and commercial sectors. If this coal usage were not converted, then SO_2 levels (both urban and rural) probably would increase with increased electrical usage. In general, the increase in air quality with increased use of electricity results from the fact that power plant stack emissions tend to be dispersed more rapidly at the high altitudes at which they are emitted whereas, the pollutants from residential, commercial, and industrial end use consumption of fossil fuels are generally emitted at essentially ground level.

National Emission Data System (NEDS) data was used in modeling the point sources for the Chicago AQCR. Standard EPA emission factors were used for determining area source emissions. While there may be some doubt as to the validity of the emission factors for small industrial and residential sources, the results of this study are relatively insensitive to those emissions as the point source and mobile source contributions are the largest.

2.1.5 Subtask 6 - Projection of the Maximum Rate of Application of Electrical Equipment

On the basis of this study it appears that the currently projected growth for both the utility industry and the electrical end use equipment manufacturing industry will be sufficient to provide a 110% increase in electrical generating capacity, a 120% increase in the production of electrical space heating equipment, a 60% increase in the production of electrical water heating equipment, and a 20% increase in electrical cooking equipment over 1974 production figures by 1985. These increases would be necessary to insure that from the present until 1985 all new installations of end use equipment in the residential and commercial sectors would be electrical. These increases would not provide for replacement of existing fossil fuel-fired equipment that required replacement. Existing fossil fuel-fired equipment requiring replacement would have to be replaced by new fossil fuel equipment. These same assumptions would require a 330% increase in electrical generating capacity, a 260% increase in the rate of production of electrical space heating equipment, a 140% increase in the rate of production of electrical water heating equipment, and a 50% increase in the rate of production of electrical cooking equipment over 1974 production by the year 2000. These increases could be met with only a slight increase over the current projected growth in these industries.

In order to insure that all new installations of energy end use equipment in the commercial and residential sectors utilize electrical equipment and that all existing fossil fuel-fired equipment units are replaced by electrical equipment as they are retired a considerable expansion of new power plant construction over and above the current projected growth rate for this industry would have to occur. The utility industry would have to expand generating capacity by 220% over 1974 production by 1985 and by 450% by 2000. This is nearly twice the present projected growth for this period but is not inconsistent with the 7% growth per year that was the excepted annual growth rate for the utility industry prior to 1970. However, for a variety of reasons, discussed in detail in Section 7.0, it does not appear at the present time that new power plants can be built at this rate in the future. For this reason new power plant construction will probably be the limiting factor in determining how fast electrical equipment can be substituted for fossil fuel equipment in the residential, commercial, and industrial energy and use sectors.

The 170% increase in electrical water heating equipment production by 1985 and the 220% expansion by 2000 could probably be met with a slight growth over and above the historical growth patterns for these industries. The same would be true for electrical cooking equipment where a 90% increase in production over 1974 would be necessary by 1985 with a 150% increase by 2000. In the case of electrical space heating equipment the 400% increase in production over 1974 that would be required by 1985 could probably not be met without artificial incentives (government subsidies, tax write-offs, etc.). This constraint notwithstanding, expansion of end use equipment production facilities does not appear to be a significant constraint to increased electricity usage in the stationary energy end use sectors.

2.1.6 Subtask 7 - Definition of Equipment Costs

In Section 8.0 of this report it is shown that both the capital and operating costs of electrical end use equipment are generally higher than the capital and operating costs for comparable fossil fuel-fired equipment used in the residential, commercial, and industrial stationary energy end use sectors. For this reason it was concluded that significant consumer incentives for increased electrification of these sectors would have to be provided before any spontaneous switching from fossil fuel fired equipment to electrical equipment would occur at present energy cost ratios. The fact that fossil fuel costs are increasing more rapidly at present than electricity costs may radically change this conclusion if present pricing trends continue. In addition, if the costs for interstate natural gas and domestic crude oil were to be deregulated electrical alternatives would probably become rapidly more attractive.

2.2 Recommendations

Recommendations based on the results of the work performed to accomplish the first seven subtasks described in the introduction are presented below. In addition, in fulfillment of the eighth subtask described in the introduction, recommendations for additional work that should be conducted to enable more firm conclusions regarding the potential for the application of electrical equipment in the residential, commercial and industrial sectors are discussed.

2.2.1 Recommendations Based on the Results of this Study

On the basis of this study, it would appear that a special program to promote substantial increases in the rate of electrification of the stationary energy end use sectors should be instituted at this time. Also, emphasis should be placed on eliminating the use of clean premium fuels for electrical generation and other large industrial uses and on developing coal conversion technologies. As much domestic natural gas and oil as possible should be utilized to meet residential and commercial sector end use demands. Electrical energy substitution for fossil fuel consumption in these sectors should be utilized to the extent necessary to fill the gap between supply and demand until coal conversion technologies can begin to fill this ever widening gap.

It should be noted that these recommendations are made without consideration for the relative economics of coal conversion to liquid and gaseous fuels and coal conversion to electricity. These recommendations are based solely on the basis of the results of the efficiency and environmental analyses made as part of this study.

Although the energy efficiency of satisfying residential space heating demands using high Btu gas produced from coal is generally higher and the gross air, water, and solid emissions are generally lower than those for electrical space heating, the synthetic fossil fuel route may be by far the more expensive of the two options. If this is the case increased electrification may become an attractive alternative and should be implemented for purely economic reasons since it has been demonstrated in this study that even though the gross air emissions from power generation are greater than those from coal conversion there is no significant degradation of either rural or urban air quality associated with intensive electrical substitution in the stationary sectors.

2.2.2 Recommendations for Future Work

Radian's recommendations for additional work which should be done, using this study as a basis, in order to enable firm conclusions regarding the potential for the application of increased electrical equipment usage are summarized below:

- Additional fuel usage assessments should be made which consider the mobile sources as well as the stationary sources. A more intensive breakdown of fuel usage in the industrial sector should be made so that the potential for fuel switching from one fossil fuel to another (specifically gas or oil to coal) can be evaluated as an alternative in addition to electrical substitution.

- Definitions of alternative fuel supply and end use scenarios and alternative end use equipment should be made which consider ways of utilizing fossil fuels more efficiently and cleanly in addition to considering the electrical alternatives to fossil fuel end uses. An example of this would be examining catalytic burners as a more efficient and cleaner method of utilizing natural gas.

- An evalution of the overall fuel supply and end use module scenarios identified in this study should be made using the latest efficiency and environmental impact data generated by the environmental assessment studies presently being initiated by EPA. This data should be used to expand the scope of the environmental assessments which in the present study d[illegible] include such important considerations as the emissions of carcinogens and heavy metals. Economics should be included in the various fuel supply scenario evaluations.

- Assessments of the impact of intensive electrification on urban and rural ambient air quality should be made for additional Air Quality Control Regions (AQCR's). These assessments should involve some replacement of mobile source fossil fuel consumption with electricity usage. The base case for such assessments should recognize the fact that demand for domestic natural gas and crude oil will exceed supply and that this demand will be met in the future by synthetic fuel production. The required synthetic fuel production facilities should be sited within the AQCR being modeled for a fairer comparison with the case in which this difference is supplied by electricity generated by power plants cited in the AQCR.

- A parametric study of the basic assumptions used in the ambient air quality assessment made in this report should be made. Of particular importance would be examining the effect of various mixes of nuclear and coal fired generating facilities instead of using all coal fired facilities to provide the additional electricity required for intensive electrification as was done in the present study.

- A more in depth analysis of the maximum rate at which the nation's electrical generating capacity could be expanded should be made. The specific capital, fuel, water, and manpower requirements, for various levels of expansion should be assessed. The same type of intensive analysis should be performed for the industries which manufacture the end use equipment.

- The work done in this study to define and compare equipment costs for the fossil fuel and electric end use equipment should be expanded to include alternative fossil fuel end use equipment that would allow fossil fuels to be utilized in a more efficient and a more environmentally sound fashion.

In summary, Radian recommends that EPA initiate a study which would use the work presented in this report as a basis and would expand the original scope of work of this study to consider not only electrical substitution but also fuel switching and fossil fuel end use equipment upgrading as part or all of a plan for achieving national energy self sufficiency. This program should have as a goal determining a scenario for energy self sufficiency which is not only environmentally sound but superior from an economic as well as an energy efficiency viewpoint.

3.0 FUEL USAGE ASSESSMENT

As discussed in the introduction, one of the major goals of this program was to determine the extent to which electricity could be substituted for clean fossil fuels in stationary use sectors at the present time and in selected years through the year 2000. In order to accomplish this task, the available literature was surveyed to obtain data on both existing patterns of fossil fuel consumption in the residential, commercial and industrial sectors, and projections of future fuel demands in each of these sectors. The results of this fuel usage survey are presented in this section.

The organization of this section reflects the procedure used to perform this task. In Section 3.1, a detailed breakdown of energy end use for the year 1968 is presented. The Stanford Research Institute (SRI) report on U.S. energy consumption patterns (ST-186) was the primary source of this information. Since the SRI data were given for the year 1968, it was necessary to project these consumption figures forward to the years of interest here for purposes of assessing electrical substitution possibilities. The results of Radian's energy use projections are presented in Section 3.2.

It should be noted here that throughout this report, unless stated otherwise, electrical energy is expressed as net electricity (i.e., converted using 3413 Btu/kwh). With this approach, electrical generation losses are charged against the electrical generation category.

3.1 Energy Use in 1968

The three major energy end use categories considered in this survey were the residential, commercial and industrial sectors. The only stationary use sector not included in this group is the electrical generation category.

3.1.1 End Use Breakdown - 1968

A breakdown of the energy used in the residential and commercial sectors in the year 1968 is presented in Table 3-1. The data reported in this table are taken directly from SRI. It is fairly obvious from these data that an assessment of electrical substitution possibilities in the residential and commercial sectors can be made without any further breakdown of the SRI figures.

This is not true in the case of the industrial sector. Shown in Table 3-2 are the SRI figures for industrial energy use in 1968. In this sector, the direct heat category is the only area in which any potential for electrical substitution exists. Unfortunately, the degree of substitution possible in direct heating applications could not be determined from SRI data alone. As a result, a further breakdown of the energy used for direct heat in the industrial sector was attempted.

Radian's breakdown of energy use for direct heat in the industrial sector in 1968 is presented in Table 3-3. Details of the procedures used to obtain these figures are summarized in Appendix A.

TABLE 3-1

1968 RESIDENTIAL AND COMMERCIAL ENERGY USE*

(10^{12} Btu/yr)

END USE	COAL	OIL	GAS	TOTAL FOSSIL FUEL	NET ELECTRICITY	TOTAL ENERGY
Residential						
Space Heat	-	2988	3236	6224	163	6387
Water Heating	-	146	979	1125	222	1347
Cooking	-	49	325	374	96	470
Clothes Drying	-	9	58	67	57	124
Refrigeration	-	-	5	5	249	254
Air Conditioning	-	-	3	3	153	156
Other	-	-	-	-	450	450
TOTAL	-	3192	4606	7798	1390	9188
Commercial						
Space Heat	568	2405	1209	4182	-	4182
Water Heating	-	-	422	422	84	506
Cooking	-	-	117	117	8	125
Air Conditioning	-	-	97	97	370	467
Refrigeration	-	-	-		244	244
Feedstock	-	984	-	984	-	984
Other	-	-	-	-	373	373
TOTAL	568	3389	1845	5802	1079	6881
TOTAL RESIDENTIAL & COMMERCIAL	568	6581	6451	13600	2469	16069

*Source: (ST-186)

TABLE 3-2

1968 INDUSTRIAL ENERGY USE*

(10^{12} Btu/yr)

END USE	COAL	OIL	GAS	TOTAL FOSSIL FUEL	NET ELECTRICITY	TOTAL ENERGY
Process Steam	2349	1986	5797	10132	-	10132
Direct Heat	3025	808	2771	6604	130	6734
Feedstock	147	1600	455	2202	-	2202
Electric Drive	-	-	-	-	1958	1958
Electric Process	-	-	-	-	285	285
Electric Generating	95	80	235	410	-150	260
Other	-	-	-	-	80	80
TOTAL	5616	4474	9258	19348	2303	21651

*Source: (ST-186)

TABLE 3-3

1968 INDUSTRIAL DIRECT HEAT BREAKDOWN*

(10^{12} Btu/yr)

INDUSTRY	COAL	OIL	GAS	TOTAL FOSSIL FUEL	NET ELECTRICITY	TOTAL ENERGY
Iron & Steel	2147	193	587	2927	-	2927
Aluminum	ua	ua	ua	80	-	80
Chemicals	ua	ua	ua	560	-	560
Refining	-	540	1070	1610	-	1610
Food	126	71	270	467	-	467
Paper	-	-	4	4	-	4
Cement	ua	ua	ua	597	-	597
Glass	ua	ua	ua	108	-	108
Other	ua	ua	ua	251	130	381
TOTAL	3025	808	2771	6604	130	6734

*Source: See Appendix A

ua - unavailable

In the following section, electrical substitution possibilities in the residential, commercial and industrial sectors are discussed in more detail.

3.1.2 Potential for Electrical Substitution

From Table 3-1 it can be seen that all fossil fuel use in the residential category could be converted to electricity since some electricity is already used for each of the end uses shown. Similar reasoning for the commercial category indicates that all fossil fuel uses except "feedstock" could be converted to electricity. Thus, in 1968, a possible premium fuel savings of 12,616 trillion Btu could have been realized through electrification in the residential and commercial categories.

In the industrial sector, only two end use categories have any potential for electrical substitution. These are the direct heat and process steam categories. Due to the inefficiencies involved, it is unlikely that process steam would ever be produced electrically in significant quantities. As a result, the only reasonable industrial end use available for conversion to electricity is the direct heat category. Referring to Table 3-3, it can be seen that total fossil fuel usage for direct heat in the industrial sector was 6604 trillion Btu in 1968, of which 2196 trillion Btu were coal, coke and hydrocarbon injection gas used in blast furnaces in the iron and steel industry (see Appendix A). Since this latter end use is not switchable to electricity, the maximum conversion possible in the industrial sector in 1968 was 4408 trillion Btu. It is important to realize that this number is actually an upper bound since all of the fossil fuel end uses shown in Table 3-3 cannot be satisfied by electricity at the present time due to a lack of available hardware for substitution. The impact of this equipment availability constraint upon switching possibilities in the industrial direct heat category is covered in greater depth in Section 4.0 of this report.

A summary of these 1968 fossil fuel substitution possibilities is presented in Table 3-4. From the data shown in this table, it can be seen that approximately half of the demands which were satisfied by fossil fuels in 1968 in the sectors considered could have been satisfied by electrical energy. The potential for electrical substitution was greatest in the residential sector where essentially 100% of the fossil fuel energy consumed in 1968 could have been replaced with electricity. The industrial category was the area in which the potential for electrical substitution was the smallest.

TABLE 3-4

FOSSIL FUEL SWITCHING POSSIBILITIES IN 1968

CATEGORY	TOTAL FOSSIL FUEL USAGE 10^{12} Btu/yr.	SWITCHABLE AMOUNT, 10^{12} Btu/yr	PERCENTAGE OF TOTAL FOSSIL FUEL USED IN CATEGORY WHICH IS SWITCHABLE
Residential	7798	7798	100
Commercial	5802	4818	83
Industrial	19348	<4408	<23
TOTAL	32948	<17024	<52

3.2 Present and Future Energy Use

The 1968 fuel use breakdown described in the previous section was used as a basis for predicting the extent of possible electrical substitution in both present and future years. It should be noted here that the amount of fossil fuels that are deemed switchable in this context are based solely on the capability of electricity to perform the same task as the fossil fuel which it replaces. Since no consideration is given to the rates at which electrical equipment could be substituted or additional generating capacity installed, these estimates must be considered to be upper bounds.

The years for which this analysis was performed are 1972, 1985 and 2000. These three years were chosen for a variety of reasons. The year 1972 was chosen to represent the present case since it is the latest year for which real fuel consumption data were available. The year 2000 was defined in the contract task order as being the final year to be considered. The year 1985 was chosen as an intermediate year for 2 reasons:

(1) Reasonably accurate predictions of energy demands are possible for 1985.

(2) Newly developing energy technologies will probably not have a significant effect on energy use patterns until sometime after 1985.

3.2.1 End Use Breakdown

Radian's projections of energy end use in the residential, commercial and industrial sectors in the years 1972, 1985 and 2000 are presented in Tables 3-5, 3-6, and 3-7. The numbers

TABLE 3-5

ESTIMATED 1972 ENERGY USE PATTERN

(10^{12} Btu/yr)

End use	Coal	Oil	Gas	Total fossil fuel	Electricity	Total net energy
Residential						
Space heat	-	3000	3722	6722	345	7067
Water heating	-	146	1135	1281	239	1520
Cooking	-	49	311	360	98	458
Clothes drying	-	11	81	92	68	160
Refrigeration	-	-	10	10	318	328
Air conditioning	-	-	3	3	245	248
Other	-	-	-	-	500	500
Total	-	3206	5262	8468	1813	10281
Commercial						
Space heat	387	2462	1621	4470	-	4470
Water heating	-	-	439	439	86	525
Cooking	-	-	131	131	9	140
Air conditioning	-	-	189	189	448	637
Refrigeration	-	-	-	-	245	245
Feedstock	-	1000	-	1000	-	1000
Other	-	-	-	-	877	877
Total	387	3462	2380	6229	1665	7894
Total residential and commercial	387	6668	7642	14697	3478	18175

TABLE 3-5 (continued)-ESTIMATED 1972 ENERGY USE PATTERN

(10^{12} Btu/yr)

End use	Coal	Oil	Gas	Total fossil fuel	Electricity	Total net energy
Industrial						
Process steam	1386	2391	6681	10458	-	10458
Direct heat	2702	808	3181	6691	147	6838
Iron & steel	-	-	-	(2891)	-	(2891)
Aluminum	-	-	-	(82)	-	(82)
Chemicals	-	-	-	(576)	-	(576)
Refining	-	-	-	(1656)	-	(1656)
Food	-	-	-	(480)	-	(480)
Paper	-	-	-	(4)	-	(4)
Cement	-	-	-	(614)	-	(614)
Glass	-	-	-	(111)	-	(111)
Other direct heat	-	-	-	(277)	-	(277)
Feedstock	120	2369	474	2963	-	2963
Elec. drive	-	-	-	-	2101	2101
Elec. process	-	-	-	-	299	299
Elec. gen.*	58	100	255	413	-142	271
Other	-	-	-	-	88	88
Total Industrial	4266	5668	10591	20525	2493	23018

*Generation losses are included.

TABLE 3-6

ESTIMATED 1985 ENERGY USE PATTERN

(10^{12} Btu/yr)

End use	Coal	Oil	Gas	Total fossil fuel	Electricity	Total net energy
Residential						
Space heat	-	3186	4730	7916	1312	9228
Water heating	-	250	1600	1850	400	2250
Cooking	-	50	342	392	110	502
Clothes drying	-	30	217	247	150	397
Refrigeration	-	-	15	15	750	765
Air conditioning	-	-	3	3	770	773
Other	-	-	-	-	506	506
Total	-	3516	6907	10423	3998	14421
Commercial						
Space heat	100	3684	2681	6465	-	6465
Water heating	-	-	500	500	124	624
Cooking	-	-	232	232	22	254
Air conditioning	-	-	680	680	1380	2060
Refrigeration	-	-	-	-	400	400
Feedstock	-	1600	-	1600	-	1600
Other	-	-	-	-	1876	1876
Total	100	5284	4093	9477	3802	13279
Total residential and commercial	100	8800	11000	19900	7800	27700

TABLE 3-6 (continued) - ESTIMATED 1985 ENERGY USE PATTERN
(10^{12} Btu/yr)

End use	Coal	Oil	Gas	Total fossil fuel	Electricity	Total net energy*
Industrial						
Process steam	2278	2474	9209	13961	-	13961
Direct heat	2743	808	4331	7882	428	8310
Iron & steel	-	-	-	(3472)	-	(3472)
Aluminum	-	-	-	(95)	-	(95)
Chemicals	-	-	-	(668)	-	(668)
Refining	-	-	-	(1922)	-	(1922)
Food	-	-	-	(557)	-	(557)
Paper	-	-	-	(5)	-	(5)
Cement	-	-	-	(713)	-	(713)
Glass	-	-	-	(129)	-	(129)
Other direct heat	-	-	-	(321)	-	(321)
Feedstock	129	5828	472	6429	-	6429
Elec. drive	-	-	-	-	5060	5060
Elec. process	-	-	-	-	669	669
Elec. gen.*	-	20	288	308	-103	205
Other	-	-	-	-	236	236
Total Industrial	5150	9130	14300	28580	6290	34870

*Generation losses are included

TABLE 3-7

ESTIMATED 2000 ENERGY USE PATTERN

(10^{12} Btu/yr)

End use	Coal	Oil	Gas	Total fossil fuel	Electricity	Total net energy
Residential						
Space heat	-	4026	5779	9805	2535	12340
Water heating	-	316	1955	2271	773	3044
Cooking	-	63	418	481	212	693
Clothes drying	-	38	265	303	290	593
Refrigeration	-	-	18	18	1449	1467
Air conditioning	-	-	4	4	1487	1491
Other	-	-	-	-	978	978
Total	-	4443	8439	12882	7724	20606
Commercial						
Space heat	-	4655	3276	7931	-	7931
Water heating	-	-	611	611	239	850
Cooking	-	-	283	283	43	326
Air conditioning	-	-	831	831	2666	3497
Refrigeration	-	-	-	-	773	773
Feedstock	-	2022	-	2022	-	2022
Other	-	-	-	-	3625	3625
Total	-	6677	5001	11678	7346	19024
Total residential and commercial	-	11120	13440	24560	15070	39630

TABLE 3-7 (continued) - ESTIMATED 2000 ENERGY USE PATTERN
(10^{12} Btu/yr)

End use	Coal	Oil	Gas	Total fossil fuel	Electricity	Total net energy
Industrial						
Process steam	2964	3976	13394	20334	-	20334
Direct heat	3568	1298	6300	11166	1056	12222
Iron & steel	-	-	-	(4919)	-	(4919)
Aluminum	-	-	-	(135)	-	(135)
Chemicals	-	-	-	(947)	-	(947)
Refining	-	-	-	(2722)	-	(2722)
Food	-	-	-	(790)	-	(790)
Paper	-	-	-	(7)	-	(7)
Cement	-	-	-	(1009)	-	(1009)
Glass	-	-	-	(183)	-	(183)
Other direct heat	-	-	-	(454)	-	(454)
Feedstock	168	9366	687	10221	-	10221
Elec. drive	-	-	-	-	12478	12478
Elec. process	-	-	-	-	1650	1650
Elec. gen.*	-	20	419	439	-146	293
Other	-	-	-	-	582	582
Total Industrial	6700	14660	20800	42160	15620	57780

*Generation losses are included

shown in parentheses in the industrial sector listings result from Radian's detailed breakdown of the direct heat category. Since the totals for this category are recorded under direct heat, the numbers in parentheses should not be added to the other figures in the columns when calculating total industrial sector energy use.

The energy use projections shown in Table 3-5 are based on consumption data for 1972 obtained from the Bureau of Mines (BOM) (CR-067). The 1985 and 2000 projections are derived from data published by the Department of Interior (DOI) (DU-044). Usage patterns which were discussed in the previous section were also used to obtain the figures shown in Tables 3-5, 3-6 and 3-7.

The BOM data and DOI energy use projections were both broken down according to fuel type and end use. The end use categories used by BOM and DOI are residential and commercial, industrial, electric utility, transportation, and other. The categories applicable to the stationary sector are residential and commercial, industrial, and electric utility. The BOM and DOI projections of residential and commercial, and industrial energy use were allocated to specific end uses for 1972 and 1985 by projecting the SRI 1968 data to 1972 and 1985. This was done by using the 1960 and 1968 data to calculate annual average growth rates for each end use in SRI. Since the total energy use calculated by this method tended to be somewhat high, the results were scaled down to produce the general category totals specified by BOM and DOI. However, before scaling, obvious discrepancies, such as small end uses with high growth rates resulting in unusually high uses in later years, were corrected. The end use profile for the year 2000 was assumed to be identical to the 1985 case so that end use consumption figures for the year 2000 were obtained by scaling up 1985 consumption data.

Radian's projections of electric utility fuel usage for the year 1972, 1985 and 2000 are presented in Table 3-8. The 1972 data shown in the table were taken from the BOM survey while those for 1985 and 2000 were taken from the DOI projections. Slight modification of the DOI data base was necessitated by the fact that their projections did not consider geothermal power plants. Since this source of energy is now expected to produce significant amounts of electrical power in the future, it was included to insure that fossil fuel usage figures would not be unreasonably inaccurate. The additional energy attributed to geothermal sources in Table 3-8 was deducted from the fossil fuel usage data published by DOI in such a way that total projected energy use remained constant. This fossil fuel reduction was confined to the oil and gas categories since these are the two fossil fuels which are currently in short supply.

The amount of energy that geothermal sources are expected to provide is a hotly contested issue at present with estimates differing as much as an order of magnitude. Three of these estimates are shown for 1985 and 2000 in Table 3-9. The figures shown in the projections in Table 3-8 are 1400 and 5500 trillion Btu/yr for 1985 and 2000, respectively. These numbers resulted from assuming 19,000 MW and 75,000 MW of installed geothermal generating capacity in 1985 and 2000, respectively. A use factor of 85% and heat rate of 9861 Btu/kwh were used in both cases to convert these geothermal electrical generating capacity estimates into their fossil fuel consumption equivalents.

The Department of Interior's energy use projections were chosen as bases for calculating 1985 and 2000 energy use patterns for three reasons, First, the DOI projections specifically included both years in question. Second, their fuel use and category breakdown was the most comprehensive available. Finally, and most importantly, the total energy projected is approximately the median value of all projections considered. This last point is illustrated by Table 3-10.

TABLE 3-8

ELECTRIC UTILITY ENERGY USE PATTERNS

(10^{12} Btu/yr)

Year	Coal	Oil	Gas	Total fossil fuel	Nuclear	Hydro	Geo-thermal	Total gross energy	Electricity distributed	Total generation losses
1972	7836	3134	4102	15072	575	2912	-	18559	5988	12571
1985	14220	5950	2750	22920	11750	4320	1400	40390	14090	26300
2000	17520	2040	140	19700	49230	5950	5500	80380	30690	49690

TABLE 3-9

GEOTHERMAL ENERGY PROJECTIONS

(10^{12} Btu/yr)

Source of Projection	1985	2000
Atomic Energy Commission (RA-166)	1500	6000
National Petroleum Council (NA-179)		
Historical growth	514	-
Stimulated growth	1395	-
Environmental Science and Technology (MA-400)		
Lower bound	1395	5507
Upper bound	9692	29003

TABLE 3-10

ENERGY USE PROJECTIONS

(10^{15} Btu/yr)

Source of Projection	Year Published	1985	2000
Electrical World (FI-081)	1974	116	-
Department of Interior (DU-044)	1972	116	192
Ford Foundation (FO-027)	1974		
Historical growth		115	185
Technical fix		96	118
Zero growth		93	100
National Petroleum Council (NA-175)	1972		
High growth		130	215
Medium growth		125	200
Low growth		112	170
National Academy of Engineering (NA-174)	1974		
Historical Growth		123	-
With conservation		108	-
Atomic Energy Commission (RA-166)	1974		
Historical growth		121	-
With conservation		106	-

New energy sources other than geothermal were considered, but were not included in the projections because of their limited development potential or the lack of development of the technology required to make them feasible. These energy sources include solar energy, energy from agriculture, tidal energy, and municipal trash combustion. Solar energy, although widely available, was excluded because a technological breakthrough will be necessary before it can compete economically with conventional energy sources in the generation of electricity. The direct generation of electricity from solar energy using solar cell technology presently available costs on the order of $2 to $5 per kwh (NA-179) which is about 1000 times that of conventional power sources. Direct use of solar energy is not expected to provide significant amounts of energy in the near future. The factors limiting widespread use of solar heating and cooling are high initial cost and the intermittent availability of the energy source.

Energy from agriculture was excluded because at present it is a limited resource with no more than 3000 trillion (NA-179) Btu/yr available from combustion of agricultural residues. Although the energy available from this source could be increased significantly by planting crops to be used to make fuel, many years of research and development would be necessary to accomplish it. Thus, since this technology is not well defined, this form of energy was not included in the projections.

Tidal energy was excluded because there are very few sites in the United States where this energy could be extracted economically. If developed to the practical limit, tidal energy could provide only 0.2% (NA-179) of the energy required in the U.S. in 1985.

Municipal trash is another energy source that was excluded due to its limited capabilities. It has been estimated (NA-179) that the maximum energy available from this source is 1600 trillion Btu/yr. However, 65% of the heating value of trash is due to its paper content which will decrease as more paper products are salvaged for recycling. Thus, since at best this energy resource represents less than 2% of the 1985 energy requirements, it is not included in the projections.

3.2.2 Potential For Electricity Substitution

By utilizing a procedure similar to that discussed in Section 3.1.2, the fossil fuel uses that could be satisfied by electricity in the years 1972, 1985 and 2000 were estimated. These substitution possibility projections are summarized in Table 3-11.

In general, the guidelines used to generate the figures shown in Table 3-11 from the data presented in Tables 3-5, 3-6 and 3-7 were the following:

- Fossil fuel end uses currently being satisfied by electricity in the residential and commercial sectors were assumed to be convertible in future years. All end uses except "feedstock" in the commercial sector were therefore considered to be switchable in this context.

- In the industrial sector, only those fossil fuels which were allocated to the direct heat category were considered to be switchable.

- In the case of the 1968 data discussed in Section 3.1.2, fossil fuels used to provide direct heat for blast furnace operation in the iron and steel industry were not considered to be switchable. Since detailed breakdowns of direct heat requirements were not given in any of the sources considered in this subtask, it was necessary to assume that the same fraction of fossil fuel direct heat attributable to blast furnace operation in 1968 also applied to the years 1972, 1985 and 2000. Industrial sector switching possibilities shown in Table 3-11 were obtained using this basis and the data given in Tables 3-5, 3-6 and 3-7.

As implied by the inequalities given in Table 3-11, industrial sector figures should be considered to be upper bounds since some of the fossil fuels used in that sector are not switchable due to a lack of available electrical hardware for substitution. The impact of this equipment availability constraint upon industrial sector substitution possibilities is discussed in detail in Section 4.0 of this report.

TABLE 3-11

PRESENT AND FUTURE FOSSIL FUEL SWITCHING POSSIBILITIES

CATEGORY	TOTAL FOSSIL FUEL USAGE 10^{12} Btu/yr.	SWITCHABLE AMOUNT 10^{12} Btu/yr.	PERCENTAGE OF TOTAL FOSSIL FUEL USED IN CATEGORY WHICH IS SWITCHABLE
1972			
Residential	8468	8468	100
Commercial	6229	5229	84
Industrial	20525	<4596	<22
TOTAL	35222	<18293	<52
1985			
Residential	10423	10423	100
Commercial	9477	7877	83
Industrial	28580	<5334	<19
TOTAL	48480	<23634	<49
2000			
Residential	12882	12882	100
Commercial	11678	9656	83
Industrial	42160	<7557	<18
TOTAL	66720	<30095	<45

4.0 DEFINITION OF ALTERNATIVES

In this section fuel supply options and end use equipment alternatives are discussed. Each of these topics is covered in separate subsections below.

4.1 Methodology and Selection of Fuel Supply Scenarios

Before an energy resource can be utilized to satisfy the demands of major consumers, a series of operations involving

- the extraction of the resource from the ground,
- the conversion of the resource into a form which is suitable for end use consumption, and
- the transportation of the raw or converted resource to appropriate end use locations

must take place. All of the end use fuels consumed in this country are produced as products of energy supply chains composed of these three generalized unit steps or operations.

The results of the fuel usage assessment subtask previously discussed indicated that electricity, fuel oil, and natural gas are the three major fossil fuel end use energy forms consumed in the residential, commercial, and industrial sectors. Although this number of significant end use energy forms is small, there exists an almost unlimited number of potential methods of producing these fuels due to the existence of

- a variety of energy resource raw materials which occur in multiple forms,
- processing options which make it possible to derive a wide spectrum of end use fuels from each resource type, and

- multiple options for transporting solid, liquid, and gaseous fuels.

The analysis of any complex system that is composed of such a variety of optional components is considerably simplified by the use of a framework which permits the division of the system into its component parts. In this study, such a framework has been provided through the construction of sets of fuel supply scenarios.

A scenario is defined here to include all of the individual steps required to extract a raw material from the ground, process it into the desired end use form and deliver it to the point of end use. More specifically, each scenario is characterized by:

(1) the source or location of the resource -- Illinois, Gulf Coast, etc.;

(2) the type of resource -- coal, oil shale, natural gas, etc.;

(3) resource recovery method -- underground mining, oil well, etc.;

(4) transportation mode(s) -- railway, pipeline, etc.;

(5) processing/conversion mode -- coal liquefaction, coal-fired power plant, etc.;

(6) end use energy form -- liquid fuels, electricity, etc.

(7) end use location -- Chicago, etc.;

In some cases, fuel supply scenarios can be relatively simple. If a resource is consumed in essentially its raw form at a location close to the resource deposit, a single extraction step followed by a single transportation step may be all that is involved. On the other hand, certain fuels may require complex processing sequences which are composed of multiple conversion and transportation steps. Once this general method of characterizing energy supply systems was established, specific fuel supply scenarios had to be selected for detailed analysis in subsequent phases of the study. The bases which were used for this selection are summarized below.

First, all significant domestic fossil fuel resources which could be used to satisfy stationary sector demands for coal, fuel oil, natural gas or electricity were identified. Fossil fuel resources included in this group included coal, oil shale, crude oil and natural gas. Next, the fuel production technologies capable of producing the end use fuels of interest were identified. Two general classes of technologies were considered here:

(1) methods which are currently being widely used to supply the end use fuels of interest, e.g., coal-fired power plants to produce electricity;

(2) developing technologies which are expected to contribute significantly to the production of these fuels in the near term future, e.g., coal gasification to produce SNG.

By following these general guidelines, the fuel supply options shown in Table 4-1 were generated. It should be noted that nuclear alternatives were not considered.

TABLE 4-1

SIGNIFICANT POTENTIAL FOSSIL FUEL RESOURCES FOR END USE ENERGY PRODUCTION DURING THE PERIOD 1970-2000

Source	End Use Energy Form
1. Natural Gas	Electricity
2. Fuel Oil	Electricity
3. Coal	Electricity
4. Low Sulfur Coal	Electricity
5. Low Btu Gas (Coal)	Electricity
6. Physically Cleaned Coal	Electricity
7. Chemically Cleaned Coal	Electricity
8. Crude Oil	Fuel Oil
9. Shale Oil	Fuel Oil
10. Liquefaction (Coal)	Fuel Oil
11. Natural Gas	Gas
12. High Btu Gas (Coal)	Gas

Once this list of fuel supply options was assembled, a basis for selecting specific resource extraction, processing and transportation steps involved in the production of each end use fuel had to be established. The guidelines used by Radian to formulate specific fuel supply scenarios from the list of options shown in Table 4-1 are summarized below.

In the ambient air impact assessment subtask which is described in a later section of this report, the impact of increased electrification upon the quality of the ambient air in a typical AQCR is considered. Selected for use in that assessment subtask was the AQCR which includes the Chicago, Illinois Metropolitan Area. This selection was made for a variety of reasons. Among these were the following:

(1) Chicago is a large, centrally located demand center.

(2) Existing patterns of energy consumption in Chicago are similar to national averages.

(3) The NEDS data base for Chicago area point sources was already available to Radian.

The use of Chicago as the example demand center creates an interesting set of fuel supply alternatives. Abundant reserves of high sulfur coal are found in Illinois. The tradeoffs involved in using this locally available "dirty fuel" versus the alternative of burning fuel oil produced from oil extracted in the Gulf Coast area is one example of the kind of case study which is made possible by the use of Chicago as the example center. In addition, since Chicago had been chosen to serve as the basis for ambient air impact assessment activities, its use as a basis for scenario construction seemed reasonable as well.

Specification of the resource extraction, processing, and transportation steps needed to satisfy the fuel supply options listed in Table 4-1 was a reasonably straightforward exercise once Chicago was selected as the basis for scenario construction. Shown in Table 4-2 are the specific modules which were used by Radian to construct each fuel supply scenario. General guidelines which were used in this effort are discussed below.

Since the Gulf Coast area supplies a considerable fraction of the gaseous and liquid fuels consumed in the Chicago area, natural gas and crude oil were assumed to be transported by pipeline from producing regions located along the Gulf Coast. The source of low sulfur coal for electrical generation was assumed to be Wyoming coal that was surface mined and transported by rail. All other coal requirements were assumed to be satisfied by high sulfur Illinois coal that was mined underground and transported to the Chicago area by rail. Coal slurry pipelines were not considered here since less than 1% of the coal presently transported in this country is moved by this method. Furthermore, the possible extent of future coal transportation by this method is uncertain.

To the extent that it was reasonable to do so, processing and conversion facilities (e.g., refineries, power plants) were assumed to be sited in the Chicago area. This was done so that the Chicago AQCR would be burdened with emissions resulting directly from the energy conversion activities required to produce the end use fuels consumed in that area. Although this guideline was intended to apply mainly to the case studies which were performed as part of the ambient air impact assessment subtask, fuel supply scenarios were also constructed with this general constraint in mind.

Oil shale retorting and coal cleaning operations were exceptions to this guideline. Since it is not economically feasible to transport raw oil shale over large distances, the shale oil retorting and upgrading processes necessary to produce a pipeline quality syncrude were assumed to be located at the mine site. Since the major product of a shale oil retorting/upgrading complex is essentially a fuel oil boiling range material already, a syncrude refinery in the Chicago area was not assumed to be a necessary part of this scenario. The synthetic crude oil produced in a typical coal liquefaction facility on the other hand, requires a considerable amount of downstream processing to produce liquid fuels suitable for consumption by end users.

For a variety of reasons, coal cleaning facilities are typically located close to the mining operations which supply their feedstock raw materials. This convention was recognized in the construction of scenarios S6 and S7 in Table 4-2.

In this section, the bases used by Radian to construct representative sets of fuel supply scenarios have been summarized. The techniques which were then used to calculate energy use efficiencies and environmental impacts of these scenarios are described in Section 5.0 of this report.

4.2 Conversion of Fossil-Fuel Powered Equipment to Electrical Equipment

In this section, significant results of the end use equipment alternative study are discussed. Within each of the

TABLE 4-2

FUEL SUPPLY SCENARIOS

Scenario I.D. Number	Resource	Extraction	Transport	Processing/ Conversion	Transport	Processing/ Conversion	Fuel/Energy
S-1	Gulf Coast Natural Gas	Natural Gas Well	Pipeline (Natural Gas)	None	None	Power Plant (Chicago)	Electricity
S-2	Gulf Coast Crude Oil	Oil Well	Pipeline (Crude Oil)	Refinery (Chicago)	None	Power Plant (Chicago)	Electricity
S-3	Illinois Coal	Underground Coal Mine	Rail	Power Plant (Chicago)	None	None	Electricity
S-4	Wyoming Coal	Surface Coal Mine	Rail	Power Plant (Chicago)	None	None	Electricity
S-5	Illinois Coal	Underground Coal Mine	Rail	Low Btu Gasification (Chicago)	None	Power Plant (Chicago)	Electricity
S-6	Illinois Coal	Underground Coal Mine	None	Physical Cleaning (Mine)	Rail	Power Plant (Chicago)	Electricity
S-7	Illinois Coal	Underground Coal Mine	None	Chemical Cleaning (Mine)	Rail	Power Plant (Chicago)	Electricity
S-8	Gulf Coast Crude Oil	Oil Well	Pipeline (Crude Oil)	Refinery (Chicago)	None	None	Fuel Oil
S-9	Colorado Oil Shale	Underground Shale Mine	None	Retort and Upgrade (Mine)	Pipeline (Fuel Oil)	None	Fuel Oil
S-10	Illinois Coal	Underground Coal Mine	Rail	Coal Liquefaction (Chicago)	None	Syn-Crude Refinery (Chicago)	Fuel Oil
S-11	Gulf Coast Natural Gas	Natural Gas Well	Pipeline (Natural Gas)	None	None	None	Natural Gas
S-12	Illinois Coal	Underground Coal Mine	Rail	Hi-Btu Gasification (Chicago)	None	None	Synthetic Natural Gas

three sectors studied, the potential for conversion of fossil fuel fired equipment to electrically powered equipment is considered. Also, listings are presented which summarize specific convertible end use equipment options.

4.2.1 Residential Sector Substitution Potential

A summary of residential fossil fuel usage in 1968 is presented in Table 4-3. For each of the fossil fuel-fired end uses shown in the table, electrical alternatives do exist. These alternatives are listed in Table 4-4. Also shown in this table are the thermodynamic efficiency values which are considered to be representative of the performance of each equipment item. Justification for the use of these efficiency values is discussed in Appendix B.

4.2.2 Commercial Sector Substitution Potential

In the commercial sector, major fossil fuel end uses with potential for conversion to electricity include: space heating, water heating, cooking, and air conditioning. A breakdown of commercial sector fossil fuel energy consumption by end use is presented in Table 4-5. Fossil fuel fired-equipment items currently in use in the commercial sector and their electrical alternatives are listed in Table 4-6. Thermodynamic efficiency data for each end use equipment item are also shown.

4.2.3 Industrial Sector Substitution Potential

In Section 3.0 of this report, it was shown that the direct heat category was the only end use classification in the industrial sector with significant potential for electrical substitution. For the 1968 case, after eliminating the fossil

TABLE 4-3

RESIDENTIAL ENERGY CONSUMPTION BY END USE*

End Use	Fossil Fuel Energy Consumption as Percentage of Total Fossil Fuel Used in Sector	Fossil Fuel Usage As Percentage of Total Energy Consumed for Each End Use
Space Heating	79%	97%
Water Heating	14%	83%
Cooking	5%	84%
Clothes Drying	1%	57%

99% = percentage of total fossil fuel consumed in sector accounted for by the four end uses listed.

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*Derived from data published by Stanford Research Institute (ST-186).

TABLE 4-4

ALTERNATIVE EQUIPMENT FOR RESIDENTIAL SECTOR

	Direct-Fired Fossil Fuel				Electrical	
End Use	Fuel Oil Equipment	Eff. %	Nat. Gas Equipment	Eff. %	Equipment	Eff. %
Space Heating	Furnace	55	Furnace	60	Baseboard	100
					Furnace	100
					Heat Pump	200
Water Heating	Water Heater	55	Water Heater	60	Water Heater	92
Cooking	Stove/Oven	37	Stove/Oven	37	Stove/Oven	75
					Microwave Oven	82
Clothes Drying			Clothes Dryer	50	Clothes Dryer	55

Efficiency data sources are documented in Appendix B.

TABLE 4-5

COMMERCIAL ENERGY CONSUMPTION BY END USE*

End Use	Fossil Fuel Energy Consumption as Percentage of Total Fossil Fuel Used in Sector	Fossil Fuel Usage As Percentage of Total Energy Consumed for Each End Use
Space Heating	87%	100%
Water Heating	9%	83%
Cooking	2%	94%
Air Conditioning	2%	26%

99% = percentage of total fossil fuel consumed in sector accounted for by the four end uses listed. This analysis excludes fossil fuels used for feedstocks.

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*Derived from data published by Stanford Research Institute (ST-186).

TABLE 4-6

ALTERNATIVE EQUIPMENT FOR COMMERCIAL SECTOR

	Direct-Fired Fossil Fuel						Electrical	
End Use	Coal Equip.	Eff. %	Fuel Oil Equipment	Eff. %	Nat. Gas Equipment	Eff. %	Equipment	Eff. %
Space Heat Heating	Furnace	70	Furnace	76	Furnace	77	Baseboard Furnace Heat Pump	100 100 200
Water Heating	-		Water Heater	55	Water Heater	60	Water Heater	92
Cooking	-		Stove/Oven	37	Stove/Oven	37	Stove/Oven Microwave Oven	75 82
Air Conditioning	-		-		Air Conditioning	120	Air Conditioner Heat Pump	200 200

Efficiency data sources are documented in Appendix B.

fuels allocated to blast furnace operation, it was concluded that a maximum of 4408 x 10^{12} Btu of fossil fuel energy could conceiveably have been satisfied by electricity. This value was expressed as a maximum because equipment availability constraints were not considered. When these constraints are properly accounted for the energy substitution possibilities shown in Table 4-7 are obtained. It can be seen from these data that only 1679 x 10^{12} Btu of switchable fossil fuel usage could be identified in 1968 when replacement alternatives were considered. This amount of fuel usage represents 8.6% of the total fossil fuel energy consumed in the industrial sector in 1968 as can be seen from the data presented in Table 4-9. Electrical replacement alternatives for industrial fossil fuel-fired end use hardware items are listed in Table 4-8.

Based upon the results of this energy end use alternative survey, it was concluded that significant potential exists for electrical substitution in the residential and commercial sectors. Limited availability of electrical replacement equipment in several end use categories however, severly limits industrial substitution potential. As shown by the data presented in Table 4-9, the industrial sector accounted for only about 12% (1,679 compared to 14,295 total) of the total convertible fossil fuel energy consumed in 1968.

4.3 Selection of End Use Modules

Assessing the incentives for converting from one "clean" fuel to another requires an evaluation of the energy use efficiency and environmental impact of fuel consumption at the point of end use. The fuel usage and end use equipment surveys previously discussed, provided a basis for defining significant energy end uses in the residential, commercial,

TABLE 4-7

INDUSTRIAL SECTOR FOSSIL FUEL ENERGY USES WHICH ARE REPLACEABLE BY ELECTRICITY

Industrial Sector	End Use	Fossil Fuel Type	Energy Used 1968 (10^{12} Btu)	Efficiency (%)
1. Primary Metals				
a. Iron-Steel	Steel Making	Natural Gas,	102	42*
		Fuel Oil, or LPG	32	42*
	Heating, Annealing	Natural Gas	304	11*
		Fuel Oil	56	11*
	Space Heating	Coal	18	70
		Natural Gas	128	77
		Fuel Oil	41	76
b. Aluminum	Melting, etc.	All Fossil Fuels	80	
2. Chemical	Space Heating	All Fossil Fuels	42	74
3. Food	Space Heating	Coal	126	70
		Fuel Oil and LPG	71	76
		Natural Gas	270	37
4. Stone, Clay,	Glass Melting	Natural Gas	108	17*
5. Other	Space Heating	Natural Gas Fuel oil, or CPG	251	74
TOTAL			1,679	

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*Calculated by assuming 95% efficiency for electrical equipment and ratioing process energy requirements on a [Btu/wt. of product produced] basis.

TABLE 4-8

ELECTRICAL EQUIPMENT REPLACEMENT ALTERNATIVES IN INDUSTRIAL SECTOR

Industrial Sector	End Use	Electrical Equipment	Efficiency (%)
1. Primary Metal			
a. Iron-Steel	Steel Making	Electric Arc Steel	95*
	Heating, Annealing	Electric Arc or Electric Induction Furnaces	95*
	Space Heating	Electric Furnaces	95
b. Aluminum	Melting	Electric Arc or Induction Furnaces	95*
2. Chemical	Space Heating	Electric Furnace	95
3. Food	Space Heating	Electric Furnace	95
	Cooking	Electric Stoves/Ovens Microwave Ovens	72 85
4. Stone, Clay, Glass	Glass	Electric Furnaces	95*

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*These efficiencies are assumed (based on efficiencies of other similar equipment).

TABLE 4-9

FOSSIL FUEL ENERGY CONSUMPTION IN 1968*

Sector	Convertible Fossil Fuel Energy (10^{12} Btu)	Total Fossil Fuel Energy (10^{12} Btu)	% Convertible
Residential	7,798	7,798	100
Commercial	4,818	5,802	83
Industrial	1,679	19,438	9
Totals of Above Three Sectors	14,295	33,038	42

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*Derived from data published by Stanford Research Institute (ST-166) and industrial sectors. In this section, the factors involved in the selection of specific end use alternatives for detailed consideration in the impact assessment (and comparison) phase of the program are discussed.

In the residential sector, significant end uses of fossil fuels included: space heating, water heating, cooking and clothes drying (see Table 4-3). In the scenario assessment phase of this program, however, only space heating was considered. Elimination of the other residential sector end uses was justified for the following reasons:

1) Space heating accounts for nearly 80% of the fossil fuel energy consumed in the residential sector

2) The relative thermodynamic efficiencies of residential fossil fuel fired equipment items and their electrical counterparts used for the other end uses are very similar to those for space heating (see Table 4-4). Clothes drying is an exception but it represents only 1% of the fossil fuel consumed in the sector.

3) Emissions resulting from the combustion of a given fossil fuel are essentially identical for all of the end use alternatives which utilize that fuel.

The commercial sector is very similar to the residential sector in almost all respects, with the exception of the higher relative efficiency of fossil fuel space heating. In this sector, both space heating and water heating were selected for use as representative end use modules. This decision was based upon the following factors.

1) Space heating and water heating account for 96% of the fossil fuel energy consumed in the sector.

2) The relative thermodynamic efficiencies of fossil fuel and electrically powered alternatives for space heating and water heating are different. Therefore, both end uses had to be selected to properly characterize the trade-offs involved.

3) Cooking and air conditioning were the other two most significant energy consumers in the commercial sector. Since the relative efficiencies (fossil fuel vs electric) of these alternatives were similar to one of the above, these end uses were not treated as unique cases.

Determining significant end use example cases in the idustrial sector was complicated by the fact that space heating was the only end use applicable to more than one of the major industries considered. In this sector, therefore, all end use alternatives having either

1) different relative efficiencies (fossil fuel vs electrically powered equipment), or

2) unique combinations of environmental impacts

were given detailed consideration in the impact assessment phase of the study.

5.0 ENERGY USE EFFICIENCIES AND ENVIRONMENTAL IMPACTS OF FUEL SUPPLY AND END USE SCENARIOS

In this section, the methods used to calculate overall energy use efficiencies and environmental impacts of both fuel supply and energy end use scenarios are described. Fuel supply scenarios are discussed first because a number of significant conclusions can be drawn from a consideration of fuel supply activities independent of the effects of end use consumption steps.

5.1 Fuel Supply Scenarios

5.1.1 Module Assessment Methodology

As a first step in the scenario evaluation procedure, the twelve fuel supply scenarios described in Section 4.1 were broken down into their component modules. The module list generated as a result of this activity is given in Table 5-1. Also shown in that table are the process efficiency and environmental impact data which were calculated for each module.

Impact data in Table 5-1 are expressed on the basis of 10^{12} Btu/day output of useful energy. The use of this basis has the advantage of facilitating alternative comparisons between extraction, processing, and transportation steps. The relative impact of generating electrical power using fuel oil vs natural gas is one example of the kind of comparison which can be made using the impact data presented in Table 5-1.

In order to generate the module data shown in Table 5-1, it was necessary to make several key assumptions to define

TABLE 5-1

MODULE SUMMARIES

(Basis 10^{12} Btu/Day Primary Fuel Produced or Transported)

Modules	Air Emissions (lb/Hr)					Water Emissions (10^3 Lb/Hr)				Solid Wastes (10^3 Tons/Day)	Land Use (10^3 Acres)	Water Requirements (10^6 Gal/Day)	Occupational Health (per year)			Efficiencies (%)			Ancillary Energy (10^{10} Btu/Day)
	Part	SO_2	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material	Thermal (Btu/Hr)				Deaths	Injuries	10^3 Man-days Lost	Primary Product	Total Products	Overall	
Extraction																			
Surface Coal Mine (Western Coal)	780	12	160	95	18	0	0	0	0	0	1.7	0	0.91	34	2.3	100	100	99.6	.43
Underground Coal Mine (Illinois Coal)	0	0	0	0	0	0	0	0	0	.099	13	0	4.0	600	15	100	100	99	1.0
Underground Oil Shale Mine (Colorado Oil Shale)	64	0	0	0	0	0	0	0	0	0	1.6	0	1.5	70	NA	100	100	99.5	.54
Oil Well (Gulf Coast Crude Oil)	14	.20	.25	.025	54	0	0	0	0	0	1	0	.80	77	13	100	100	100	0
Natural Gas Well (Gulf Coast Natural Gas)	52	170	2,100	59	82,000	0	0	0	0	0	12	0	0.81	77	13	100	100	100	0
Transportation																			
Railroad (Western Coal)	700	1,600	9,200	4,500	780	0	0	0	0	.57	27	0	1.0	100	9.1	99	99	91.6	8.2
Railroad (Illinois Coal)	140	310	1,800	870	150	0	0	0	0	685	6.7	0	0.85	81	7.3	99	99	97.4	1.7
Railroad (Physically Cleaned Illinois Coal)	140	310	1,800	870	150	0	0	0	0	.44	6.7	0	0.79	78	7.0	99	99	97.4	1.7
Pipeline (Crude Oil)	25	52	710	430	71	0	0	0.0064	0	0	2	0	.036	2.9	.80	100	100	99.4	.63
Pipeline (Natural Gas)	0	0	0	0	0	0	0	0	0	0	5.3	0	.0012	.015	.0078	100	100	95.3	4.9
Tank Truck (Fuel Oil)	6	12	160	100	17	0	0	0	0	0	0	0	NA	NA	NA	100	100	100	0.15
Processing/Conversion																			
Physical Coal Cleaning (Illinois Coal)	0	0	0	0	0	0	0	0	0	11	.17	3.2	1.4	29	13	83.3	81.3	83.1	.31
Chemical Coal Cleaning (Illinois Coal)	340	1,100	3,500	190	58	0.12	19	0.05	0	6.6	.12	29	1.4	29	13	90	90	90	0
Low Btu Coal Gasification (Illinois Coal)	1	2,300	1,100	32	33	0	0	0	0	7.1	.75	11	.71	14	7.5	75.8	83.9	83.9	0
Hi Btu Coal Gasification (Illinois Coal)	960	10,000	7,800	610	130	0	0	0	0	7.9	.70	25	1.8	61	17	67.9	67.9	67.9	0
Coal Liquefaction (Illinois Coal)	610	2,000	8,500	340	2,600	0	0	0	0	9.6	3.3	33	.51	9.9	2.4	62.5	62.5	62.5	0
Oil Shale Processing (Colorado Oil Shale)	450	5,300	2,000	170	2,700	0	0	0	0	165	2	21	76	29	.077	66.7	79.7	76.9	5.6
Liquefaction Syn-Crude Refinery	470	1,400	1,700	130	4,100	0.30	11	0.063	0	.0017	5.2	16	.48	35	8.4	81.5	89.5	87.1	3.5
Domestic Crude Refinery	400	1,000	1,200	90	1,000	0.25	9.1	0.052	0	.003	4.1	11	.48	35	8.6	90.4	95.4	94.7	.85
Power Plant (Chicago) (Western Coal) (Electrostatic Precipitator)	6,100	120,000	85,000	4,700	1,400	2.8	16	1.2	0	9.1	9.8	120	.32	11	5.0	32	32	32	0
Power Plant (Chicago) (Illinois Coal) (Limestone Scrubber)	9,500	74,000	97,000	5,400	1,700	3.0	17	1.3	0	55	9.8	130	.35	15	5.5	35	35	35	0
Power Plant (Chicago) (Phy. Clean Ill. Coal) (Limestone Scrubber)	5,700	41,000	91,000	5,200	1,600	3.0	17	1.1	0	42	9.8	130	.35	15	5.5	35	35	35	0
Power Plant (Chicago) (Chem. Clean Ill. Coal) (Limestone Scrubber)	8,900	29,000	89,000	5,000	1,500	3.0	17	1.3	0	36	9.8	130	.35	15	5.5	35	35	35	0
Power Plant (Chicago) (Residual Fuel Oil) (Limestone Scrubber)	63	22,000	83,000	2,400	2,400	3.0	17	1.3	0	0.9	1.7	130	.35	15	5.5	35	35	35	0
Power Plant (Chicago) (Lo Btu Fuel Gas)	1,700	58,000	68,000	1,900	110	2.8	16	1.2	0	0	1.8	120	.32	13	5.0	37	37	37	0
Power Plant (Chicago) (Natural Gas)	1,700	68	68,000	1,900	110	2.8	16	1.2	0	0	1.8	120	.32	13	5.0	37	37	37	0

NA - Not Available

bases for calculating process efficiencies and impacts. Such factors as feedstock quality, process configuration, site specific characteristics, and control strategies used obviously have a strong impact upon the results obtained in an analytical task such as that described here. Specific assumptions which were made in order to calculate the data presented in Table 5-1 are summarized in the detailed module descriptions which are presented in Appendix C. Some general guidelines which were followed in the formulation of key assumptions are discussed below.

Each module was first examined from a functional standpoint. Available technologies for accomplishing the desired extraction, conversion or transportation step were determined. These alternatives were then screened with regard to their physical similarities and differences. In cases where alternative processes used similar approaches to accomplish a given task, the selection of a representative or typical process configuration was reasonably straightforward. Where significant differences in process alternatives were noted (e.g., gasification reactor design in the case of coal gasification processes), an arbitrary selection of a basis for that processing step had to be made, with developing technologies, those which appeared to be most advanced were selected. In other cases, processes which had the highest efficiency or lowest cost were chosen to represent a given process step.

At the conclusion of this preliminary screening, a specific representative process configuration was defined for each module. Each module was then subjected to detailed process engineering analysis. Material balances were established based upon reviews of available data. Quantities and compositions of potential waste streams were defined. Auxiliary facility requirements such as boiler plants and cooling towers were determined.

These facilities were analyzed to determine their raw materials requirements and waste production rates.

The final step in the module analysis effort involved a determination of the control facilities to be applied to potential effluent sources. Control efficiencies and energy requirements for these facilities were established. The resulting controlled waste streams from all module sources were then added and tabulated in module impact tables.

It should be noted that secondary impacts such as emissions from steel mills required to supply materials for the construction of a facility were not considered. Only the impacts resulting from steady-state operation of a module facility were considered.

Generally, particulate and SO_2 emission rates were calculated by assuming compliance with Federal New Source Performance Standards. When dealing with impact categories for which no standards existed, the use of best reasonable technology which was currently available was assumed.

For all of the modules considered in this study, three different process efficiency terms were calculated. The basis for each of these efficiencies is explained below. The primary products efficiency of a module is calculated as follows:

$$\text{Primary Products Efficiency} = \frac{\text{Energy Content of Primary Module Products}}{\text{Energy Content of Module Feedstock}}$$

This efficiency term is best explained through the use of an example. In a high Btu coal gasification process, SNG is the primary fuel product. If 100 Btu of coal must be fed to the gasification module in order to produce 65 Btu of SNG, then the primary product efficiency of the module for this example is 65%. This efficiency value is important because it defines the amount of feedstock material which must be supplied to a module to derive 10^{12} Btu of the desired fuel product. Since this feedstock material must itself be produced as a product of "upstream" modules, this efficiency value is also the factor which must be used to scale-up the impacts of feedstock or fuel production activities which preceded a given module in an energy supply scenario..

The second efficiency value which was calculated for each module was a total products efficiency. This efficiency is defined as follows:

$$\text{Total Products Efficiency} = \frac{\text{Energy Content of all Module Products (Primary Products + By-Products)}}{\text{Energy Content of Module Feedstock}}$$

In the gasification example described above, if 10 Btu of by-products (char, tars, etc.) are produced along with 65 Btu of SNG for every 100 Btu of coal feed, then the total product efficiency in this example case is 75%. Although this efficiency value does not have any significance for purposes of calculating total scenario impacts, it does give an indication of the relative amounts of useful by-products produced by certain modules.

The third efficiency value which is listed in Table 5-1 is referred to as an overall efficiency. This efficiency term is calculated as follows:

$$\text{Overall Efficiency} = \frac{\text{Energy Content of all Module Products (Primary Products + By-Products)}}{\text{Energy Content of Module Feedstock + Ancillary Energy Inputs}}$$

This value is called the overall efficiency of the module because it properly accounts for all module energy inputs and outputs.

5.1.2 Fuel Supply Scenario Evaluation and Ranking

The module data listed in Table 5-1 provided the basis for subsequent calculations of overall fuel supply scenario impacts. In this section, the procedures used to determine overall scenario efficiencies and impacts are described and relative comparisons of the various scenarios considered are made.

The procedure used to calculate overall scenario impacts is best illustrated through the use of the following example case.

Shown in Figure 5-1 is a schematic representation of a hypothetical fuel supply scenario which is composed of the three modules A, B and C where A is an extraction module, B is a transportation module and C is a fuel production module.

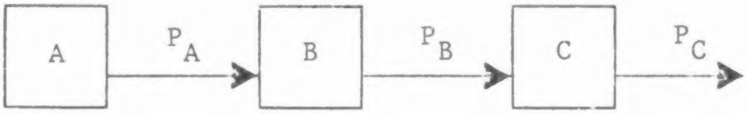

FIGURE 5-1. HYPOTHETICAL FUEL SUPPLY SCENARIO

For purposes of this discussion, it is assumed that:

- P_A, P_B and P_C are the primary fuel products of each module.
- PPE_A, PPE_B and PPE_C are their primary product efficiencies.
- $I_{i,A}$, $I_{i,B}$ and $I_{i,C}$ are the impacts resulting from the production of 10^{12} Btu/day of each primary product. The "i" subscript is being used here to indicate that there are several module impact categories to be considered, e.g., SO_2 emissions, land use, solid waste production, etc.

For this hypothetical case, overall scenario impacts would be calculated as:

$$I_{i,\substack{\text{overall}\\\text{scenario}}} = I_{i,C} + \frac{I_{i,B}}{PPE_C} + \frac{I_{i,A}}{(PPE_B)X(PPE_C)}$$

Overall scenario efficiencies were calculated by multiplying the efficiencies of their component modules. For the example case considered here,

$$PPE_{\substack{\text{overall}\\\text{scenario}}} = (PPE_A)X(PPE_B)X(PPE_C)$$

Other efficiency terms were handled in like fashion.

The results obtained by applying these procedures to the twelve fuel supply scenarios considered in this study are shown in Table 5-2. It should be noted here that all impact data shown in this table have been burdened with appropriate inefficiencies of "downstream" modules. In fuel supply scenario S1, for example, the gas well impact figures were obtained by multiplying the module emissions listed in Table 5-1 by a factor of 2.7.

$$\left(\frac{1.0}{1.0 \text{ X } .37} = 2.7\right)$$

The process efficiency and environmental impact data shown in Table 5-2 are useful not only for purposes of comparing overall scenario characteristics but also because they indicate which steps in the fuel supply chains shown make the most significant contributions to overall scenario efficiency and impact values. In fuel supply scenario S1 for example the power plant module is the major source of scenario particulate emissions. The power plant is also the major cause of the low overall efficiency shown for scenario S1.

Distribution of electricity through transmission lines and natural gas through pipelines was found to have a negligible effect on overall fuel supply scenario efficiencies and environmental impacts. For this reason, a distribution module was not included as a separate step in scenarios which produce electricity and gaseous fuels. A separate distribution module for the fuel oil case was developed however, since the impacts which result from this particular distribution step are not negligible.

Calculated scenario impacts are obviously strongly affected by the primary product efficiencies of the modules

TABLE 5-2

ENVIRONMENTAL IMPACTS OF FUEL SUPPLY SCENARIOS

(Basis 10^{12} Btu/Day Primary Fuel Produced)

Fuel Supply Scenario Number	Component Modules	Air Emissions (lb/hr)					Water Emissions (10^7 lb/hr)				Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Water Requirements (10^6 gal/day)	Occupational Health (per yr)			Efficiencies (%)		
		Part	SO_2	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material	Thermal (Btu/hr)				Deaths	Injuries	10^3 Man-days Lost	Primary Product	Total Products	Overall
S1	Natural Gas Fired Power Plant (Chicago)	1,700	68	68,000	1,900	110	3	16	1	0	0	2	120	0.32	13	5	37	37	37
	Natural Gas Pipeline to Chicago	0	0	0	0	0	0	0	0	0	0	14	0	0.003	.09	.02	100	100	95
	Natural Gas Well (Gulf Coast)	140	450	5,600	160	220,000	0	0	0	0	0	33	0	0.005	210	34	100	100	100
	Total for Scenario	1,800	520	74,000	2,100	220,000	3	16	1	0	0	49	120	0.33	220	39	37	37	35
S2	Oil-Fired Power Plant (Chicago)	63	22,000	83,000	2,400	2,400	3	17	1	0	10	4	130	0.4	15	6	35	35	35
	Crude Oil Refinery (Chicago)	1,100	2,800	3,500	260	8,600	1	26	0.15	0	0.009	12	32	1.4	100	24	90	95	95
	Crude Oil Pipeline to Chicago	79	170	2,300	1,400	230	0	0	0.02	0	0	6.1	0	0.1	9	94	100	100	99
	Oil Well (Gulf Coast)	1	1	1	0	170	0	0	0	0	0	3.2	0	2.5	240	40	100	100	100
	Total for Scenario	1,200	25,000	89,000	4,100	11,000	4	43	1.2	0	10	25	160	4.4	360	71	32	33	33
S3	Coal-Fired Power Plant (Chicago)	9,500	74,000	97,000	5,400	1,600	3	17	1	0	55	10	130	0.35	15	6	35	35	35
	Railroad to Chicago	390	890	5,100	2,500	440	0	0	0	0	1	19	0	2.4	230	21	99	99	97
	Underground Coal Mine (Illinois)	0	0	0	0	0	0	0	0	0	0.3	37	0	12	1,200	43	100	100	99
	Total for Scenario	9,900	75,000	100,000	7,900	2,000	3	17	1	0	56	66	130	15	1,400	70	35	35	34
S4	Coal-Fired Power Plant (Chicago)	6,100	120,000	84,000	4,700	1,400	3	16	1	0	9	10	120	0.32	13	5	35	37	35
	Railroad to Chicago	1,900	4,300	25,000	12,000	2,100	0	0	0	0	2	72	0	3.0	270	25	99	99	97
	Surface Coal Mine (Wyoming)	2,100	31	440	260	52	0	0	0	0	0	5	0	2.5	93	6	100	100	99
	Total for Scenario	10,000	120,000	110,000	17,000	3,600	3	16	1	0	11	87	120	5.8	380	36	37	37	34
S5	Low Btu Gas Fired Power Plant (Chicago)	1,700	58,000	68,000	1,900	110	3	16	1	0	0	2	120	.32	13	5	37	37	37
	Low Btu Gasification (Chicago)	2	6,100	3,100	87	88	0	0	0	0	20	2.0	30	1.9	38	20	76	84	84
	Railroad to Chicago	480	1,100	6,400	3,100	540	0	0	0	0	2	24	0	3.0	290	26	99	99	97
	Underground Coal Mine (Illinois)	0	0	0	0	0	0	0	0	0	0	46	0	15	1,400	53	100	100	99
	Total for Scenario	2,200	65,000	78,000	5,100	740	3	16	1	0	22	74	150	20	1,700	100	28	31	30
S6	Coal-Fired Power Plant (Chicago)	5,700	41,000	93,000	5,200	1,600	3	17	1	0	32	10	130	0.4	15	6	35	35	35
	Railroad to Chicago	390	890	5,100	2,500	440	0	0	0	0	1	19	0	2.3	220	20	99	99	97
	Physical Cleaning of Coal (Mine)	0	0	0	0	0	0	0	0	0	31	0.5	9	4.1	83	37	63	83	83
	Underground Coal Mine (Illinois)	0	0	0	0	0	0	0	0	0	0	45	0	14	1,400	51	100	100	99
	Total for Scenario	6,100	42,000	98,000	7,700	2,000	3	17	1	0	64	74	140	21	1,700	110	29	29	28
S7	Coal-Fired Power Plant (Chicago)	8,900	29,000	89,000	5,000	1,500	3	17	1	0	34	10	130	0.4	15	6	35	35	35
	Railroad to Chicago	390	890	5,100	2,500	440	0	0	0	0	1	19	0	2.4	230	21	99	99	97
	Chemical Cleaning of Coal (Mine)	980	3,300	10,000	550	170	0	53	0.14	0	13	0.5	85	NA	NA	NA	90	90	90
	Underground Coal Mine (Illinois)	0	0	0	0	0	0	0	0	0	0	41	0	13	1,300	47	100	100	99
	Total for Scenario	10,000	33,000	100,000	8,600	2,100	3	70	1.1	0	48	70	220	16	1,500	74	31	31	30
S8	Distribution (Tank Truck)	6	12	160	100	17	0	0	0	0	0	0	0	NA	NA	NA	100	100	100
	Crude Oil Refinery (Chicago)	400	1,000	1,200	90	3,000	0	9	0	0	0	4	11	0.5	35	8	90	95	95
	Crude Oil Pipeline to Chicago	28	58	790	480	79	0	0	0.01	0	0	2.2	0	0.04	3.2	0.3	100	100	99
	Oil Well (Gulf Coast)	0	0	0	0	60	0	0	0	0	0	1.1	0	.89	85	14	100	100	100
	Total for Scenario	430	1,100	2,200	670	3,200	0	9	0.01	0	0	7.3	11	1.4	120	22	90	95	94
S9	Distribution (Tank Truck)	6	12	160	100	17	0	0	0	0	0	0	0	NA	NA	NA	100	100	100
	Fuel Oil Pipeline to Chicago	25	52	710	430	71	0	0	0.01	0	0	2.0	0	0.01	2.9	0.3	100	100	99
	Retort and Upgrade (Mine)	450	5,300	2,000	170	2,700	0	0	0	0	160	2	21	0.76	79	0	67	80	77
	Underground Oil Shale Mine (Colorado)	98	0	0	0	0	0	0	0	0	0	2	0	2.2	100	NA	100	100	99
	Total for Scenario	580	5,400	2,900	700	2,800	0	0	0.01	0	160	6	21	3.0	180	0.3	67	80	75
S10	Distribution (Tank Truck)	6	12	160	100	17	0	0	0	0	0	0	0	NA	NA	NA	100	100	100
	Liquefaction Syncrude Refinery (Chicago)	460	1,400	1,700	130	4,100	0	11	0.06	0	0.064	5	16	0.5	35	8	82	90	87
	Liquefaction (Chicago)	660	2,200	19,500	380	2,900	0	0	0	0	9	4	37	0.6	11	3	62	62	62
	Railroad to Chicago	270	610	3,500	1,700	300	0	0	0	0	1	13	6	1.7	160	14	99	99	97
	Underground Coal Mine (Illinois)	0	0	0	0	0	0	0	0	0	0	26	0	7.9	800	29	100	100	99
	Total for Scenario	1,400	4,200	25,000	2,300	7,300	0	11	0.06	0	10	58	53	11	1,000	54	50	55	52
S11	Natural Gas Pipeline to Chicago	0	0	0	0	0	0	0	0	0	0	5	0	0.01	035	008	100	100	95
	Natural Gas Well (Gulf Coast)	52	170	2,100	59	82,000	0	0	0	0	0	12	0	0.81	77	13	92	92	100
	Total for Scenario	52	170	2,100	59	82,000	0	0	0	0	0	17	0	0.82	77	13	92	92	95
S12	Hi Btu Gasification (Chicago)	940	10,000	7,500	410	130	0	0	0	0	8	0.01	25	1.8	61	17	68	68	68
	Railroad to Chicago	200	460	2,600	1,300	220	0	0	0	0	0.63	10	0	1.2	170	11	99	99	97
	Underground Coal Mine (Illinois)	0	0	0	0	0	0	0	0	0	0	19	0	5.9	600	22	100	100	99
	Total for Scenario	1,100	10,000	10,000	1,700	350	0	0	0	0	8.7	29	25	8.9	780	50	67	67	65

NA - Not Available

which comprise each scenario. For this reason, electrical supply scenarios generally have greater overall impacts than fuel oil or natural gas supply scenarios due to the low conversion efficiency of the electrical power generation step. Particulate and CO emissions for example, are normally highest in those scenarios which produce electricity as an end use fuel. SO_2 and NO_x emissions are substantially higher in most electrical supply scenarios. Scenaric S1, which has low SO_2 emissions is an exception. Hydrocarbon emissions vary widely among the scenarios with significant emissions occurring in scenarios S1 and S11 due to the contribution of wellhead losses associated with natural gas production activities.

The low efficiency of the electrical generation step (which magnifies the relative effects of upstream extraction and processing modules) is not the only reason why electrical supply scenario impacts are generally higher than fossil fuel supply scenario impacts. An inspection of the figures presented in Table 5-2 readily shows that the power plants themselves are significant contributors to the total calculated impacts of electrical supply scenarios. This is particularly true in the case of the air emission figures shown. In fossil fuel supply scenarios, processing/conversion operations (e.g., refineries, liquefaction plants, oil shale retorting facilities) are usually the most significant sources of both air emissions and other impacts as well.

The twelve fuel supply scenarios considered in this study are ranked on the basis of their overall efficiencies in Table 5-3. It can be seen from this comparison that the fossil fuel supply scenarios all have higher efficiencies than the electricity supply cases shown. This is because the former are not burdened by the low 35 to 37% efficiency of the power plant module.

TABLE 5-3

RANK OF FUEL SUPPLY SCENARIOS BY OVERALL ENERGY EFFICIENCY

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall Fuel Supply Scenario Efficiency (%)
1	S11 - Natural Gas	95
2	S8 - Fuel Oil	94
3	S9 - Fuel Oil	75
4	S12- Natural Gas	65
5	S10 - Fuel Oil	52
6	S1 - Electricity	35
7	S4 - Electricity	34
8	S3 - Electricity	34
9	S2 - Electricity	33
10	S7 - Electricity	30
11	S5 - Electricity	30
12	S6 - Electricity	28

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* See Table 5-2 for scenario modules.

The first and second ranked scenarios (S11 and S8) are fossil fuel supply scenarios that originate at oil and gas wells and which utilize minimum intermediate processing. Scenarios ranked in positions 3, 4 and 5 (S9, S12 and S10) also produce fossil fuels, however, the inclusion of a shale oil processing or coal conversion module in these scenarios has lowered their efficiencies.

Electricity supply scenarios all have approximately the same overall efficiency. This is due to the fact that the power plant modules have such low efficiencies compared to the other modules used in these scenarios. It is important to realize here that power plant efficiencies were assumed to be independent of the fuel consumed by the module except for cases where fuel quality considerations necessitated the inclusion of a flue gas desulfurization unit. S1 is the most efficient of the electrical supply scenarios because negligible processing of raw natural gas is required. Also, electrical conversion energy losses are minimal for this scenario since no flue gas treatment steps are needed.

5.2 End Use Scenarios

The analysis which was presented in the previous section showed that fossil fuel supply scenarios are typically more efficient from a fuel usage point of view than electricity supply scenarios. In addition, fossil fuel supply scenarios were generally more attractive from an overall impact standpoint as well. Although this type of analysis does give an indication of the relative attractiveness of producing a given end use fuel by different methods, the production of an end use fuel per se is not the ultimate objective of the fuel supply activities considered.

The significant factor which has not been treated up to this point is the affect that end use module performance has upon overall energy supply scenario efficiencies and impacts. This aspect of the energy supply picture is considered in this section.

The criteria which were used to select representative end use modules for detailed consideration in this phase of the study were discussed in Section 4.3. Significant end use module options which were defined in that section are listed in Table 5-4, also shown in the table are the calculated impacts and efficiencies of each of the modules.

From an inspection of the data presented in Table 5-4, it can be seen that in all cases, the electrically powered end use equipment items listed are more efficient than their fossil fuel fired counterparts. Effectively, this tends to penalize fossil fuel supply scenarios relative to electricity producing alternatives. The net effect of this factor is to bring the efficiencies and impacts of fossil fuel and electrical end use scenarios closer together.

The techniques which were used to calculate overall end use scenario impacts are similar to those discussed before for the fuel supply cases. Basically, fuel supply scenario impacts were burdened by a factor of 100/PPE where PPE is the primary product (or, more specifically, primary fuel utilization) efficiency of the end use module being considered. Burdened fuel supply scenario impacts were then added to the impacts of the end use module to obtain overall end use scenario impacts. Overall scenario efficiencies were calculated by multiplying the efficiencies of the fuel supply scenarios and the end use modules involved in each case.

TABLE 5-5
END-USE MODULE SUMMARIES

End-Use Module	Air Emissions (lb/10¹² Btu)					Water Pollutants (lb/10¹² Btu)			Thermal (Btu/Btu)	Solid Wastes (10³ lb/10¹² Btu)	Land Use (10³ acres)	Water Requirement (10⁶ gallons)	Occupational Health (per year)			Efficiencies (%)			Ancillary Energy (10¹² Btu/10¹² Btu)
	Part.	SOx	NOx	CO	HC	Suspended Solids	Dissolved Solids	Organic Material					Deaths	Injuries	Man-days Lost	Primary Product	Total Products	Overall	
[illegible] Fired Space Heating	1,100	47	5,600	1,400	360	0	0	0	0	0	0	0	NA	NA	NA	--	--	60	0
Oil-Fired Space Heating	[illegible]	[illegible] (1,200)*	6,400	[illegible]	1,100	0	0	0	0	0	0	0	NA	NA	NA	--	--	55	0
Natural Gas-Fired Water Heating	1,100	47	5,600	1,400	500	0	0	0	0	0	0	0	NA	NA	NA	--	--	60	0
Oil-Fired Water Heating	1,400	19,000 (120)	8,300	2,200	1,800	0	0	0	0	0	0	0	NA	NA	NA	--	--	60	0
[illegible] Cooking	11,000	68	8,000	2,700	900	0	0	0	0	0	0	0	NA	NA	NA	--	--	37	0
[illegible] Cooking	8,1[illegible]	2,1[illegible] [illegible]	11,000	4,400	2,000	0	0	0	0	0	0	0	NA	NA	NA	--	--	37	0
[illegible] Space Heating	1,100	[illegible]	6,500	1,300	410	0	0	0	5	0	0	0	NA	NA	NA	--	--	77	0
Oil-Fired Space Heating	1,900	17,000 (120)*	23,000	1,600	1,100	0	0	0	0	0	0	0	NA	NA	NA	--	--	76	0
[illegible]	1,100	32	8,300	1,400	160	0	0	0	0	0	0	0	NA	NA	NA	--	--	60	0
[illegible] Natural Gas-Fired Space Heating	1,100	32	6,100	420	160	0	0	0	0	0	0	0	NA	NA	NA	--	--	77	0
Oil-Fired Space Heating	1,800	17,000 (1200)*	23,000	1,600	1,100	0	0	0	0	0	0	0	NA	NA	NA	--	--	8	0
[illegible]	7,100	46	1,500	1,900	160	0	0	0	0	0	0	0	NA	NA	NA	--	--	37	0
Natural Gas-Fired Steel Making	1,500	49	14,000	1,200	800	0	0	0	1	0	0	0	NA	NA	NA	--	--	42	0
Oil-Fired Steel Making	11,000	19,000 (1,000)*	42,000	7,500	2,100	0	0	0	0	3	0	0	NA	NA	NA	--	--	41	0
Natural Gas-Fired Heating and Annealing	1,700	230	47,000	8,600	1,100	0	0	0	0	0	0	0	NA	NA	NA	--	--	11	0
Oil-Fired Heating and Annealing	[illegible]	[illegible] (1,000)*	180,000	13,000	4,300	0	0	0	0	0	0	0	NA	NA	NA	--	--	11	0
[illegible]	[illegible]	[illegible]	56,000	4,100	760	0	0	0	0	0	0	0	NA	NA	NA	--	--	11	0

[illegible]

[illegible]

The results which are shown in Table 5-5 were obtained when this procedure was used to compare alternative methods of satisfying residential space heat demands. Calculated overall efficiencies and impacts of other significant end use scenarios are shown in Tables 5-6 through 5-14.

Normally there are 12 end use scenarios shown for each end use application since 12 fuel supply scenarios were considered in this study. The space heating category is an exception however.

Space heating is more complex than the other end uses examined here due to the availability of an electric heat pump (which is assumed to be twice as efficient as other types of electrical space heating equipment - see Appendix B). For this reason, electrical space heating scenarios can have overall energy efficiencies and environmental impacts which vary by a factor of two, depending on the type of end use equipment which is used. In order to give space heating scenarios utilizing electrical equipment credit for the option of using a heat pump and still examine the types of electrical equipment currently employed at most end use sites, two groups of space heat end use scenarios for each sector are presented. In one case, conventional electrical space heating equipment is assumed to be used. In the other, the heat pump case is considered.

The environmental impacts of electrical end use scenarios (excluding heat pumps) are always approximately the same as those generated by the electricity supply scenarios. This is true because electrically powered end use equipment items are generally about 100% energy efficient and the impacts of electrical equipment usage are negligible. Impacts of end use scenarios involving the combustion of fossil fuels on the

TABLE 5-5
ENVIRONMENTAL IMPACTS OF RESIDENTIAL SPACE HEAT END USE*

(Basis: 10^{12} Btu/Day Useful Energy Produced)

Scenarios	Air Emissions (lb/hr) Part.	SO_x	NO_x	CO	HC	Water Emissions (10^3 lb/hr) Suspended Solids	Dissolved Solids	Organic Material	Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Thermal (Btu/hr)	Water Requirement (10^6 gal/day)	Occupational Health (per year) Deaths	Injuries	10^3 Man Days Lost	Overall Efficiency (%)
Natural Gas Fired	1,300	42	5,600	1,400	560	0	0	0	0	0	0	0	NA	NA	NA	60
Fuel Supply Scenario S11	99	280	3,500	78	140,000	0	0	0	0	28	0	0	1	130	21	95
Fuel Supply Scenario S12	1,900	18,000	17,000	2,000	80	0	0	0	15	48	0	52	15	1,300	63	65
Totals																
S11 Plus Space Heat End Use	1,400	320	9,000	1,500	140,000	0	0	0	0	28	0	0	1	130	21	57
S12 Plus Space Heat End Use	3,200	18,000	23,000	3,200	1,100	0	0	0	15	48	0	52	15	1,300	83	39
Oil-Fired	5,400	23,000 (480)*	6,500	2,700	1,600	0	0	0	0	0	0	0	NA	NA	NA	55
Fuel Supply Scenario S8	760	2,000	4,000	1,200	5,800	0	17	.02	0	13	0	20	2.5	220	50	95
Fuel Supply Scenario S9	1,100	9,800	5,300	1,300	5,000	0	0	.02	300	11	0	38	5	140	92	75
Fuel Supply Scenario S10	2,300	7,500	47,000	4,200	13,000	0	20	.1	19	87	0	96	20	1,800	98	52
Totals																
S8 Plus Space Heat End Use	6,200	25,000	11,000	3,900	7,400	0	17	.02	0	13	0	20	2.5	220	50	52
S9 Plus Space Heat End Use	6,500	16,000	12,000	4,000	6,100	0	0	.02	300	11	0	38	5	150	NA	41
S10 Plus Space Heat End Use	7,900	31,000	52,000	5,900	15,000	0	20	.1	19	87	0	56	20	1,800	98	29
Electric (Excluding Heat Pump)	0	0	0	0	0		0	0	0			0		NA	NA	100
Totals																
S1 Plus Space Heat End Use	1,800	520	74,000	2,100	230,000	3	16	1	0	59	0	120	33	220	39	35
S2 Plus Space Heat End Use	1,700	25,000	89,000	4,100	11,000	4	41	1.2	19	23	0	160	4	360	21	33
S3 Plus Space Heat End Use	9,900	75,000	100,000	7,900	2,000	3	17	1	56	66	0	140	15	1,400	76	35
S4 Plus Space Heat End Use	10,000	120,000	110,000	17,000	1,600	3	16	1	11	67	0	120	5.8	330	36	34
S5 Plus Space Heat End Use	2,500	65,000	78,000	5,100	760	3	16	1	22	74	0	150	20	1,700	100	30
S6 Plus Space Heat End Use	6,100	42,000	98,000	7,200	2,000	3	17	1	65	74	0	150	21	1,200	110	26
S7 Plus Space Heat End Use	10,000	31,000	100,000	8,000	2,100	3	20	1	48	20	0	220	16	1,300	75	40
Electric (Utilizing Heat Pump)	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	200
Totals																
S1 Plus Space Heat End Use	910	260	37,000	1,000	110,500	1	8	1	0	29	0	58	16	110	20	70
S2 Plus Space Heat End Use	880	12,000	45,000	2,000	5,700	2	21	1	5	13	0	81	2	180	15	66
S3 Plus Space Heat End Use	4,900	37,000	51,000	3,900	1,000	2	8	1	28	33	0	65	7	630	35	68
S4 Plus Space Heat End Use	5,000	62,000	55,000	8,500	1,800	1	8	1	5	34	0	58	2.9	190	15	63
S5 Plus Space Heat End Use	1,100	31,000	39,000	2,500	370	1	8	1	11	37	0	75	10	850	50	60
S6 Plus Space Heat End Use	3,000	21,000	49,000	3,800	980	2	8	1	32	37	0	70	10	840	56	56
S7 Plus Space Heat End Use	5,100	17,000	52,000	4,000	1,000	2	15	1	24	35	0	110	8	740	37	60

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*Fuel supply scenarios are burdened by end use efficiencies.

*Combustion of 1.00 wt. % fuel oil produced by fuel supply scenario S9.

NA - Not Available

TABLE 5-6

ENVIRONMENTAL IMPACTS OF RESIDENTIAL WATER HEAT END USE†

(Basis: 10^{12} BTU/day Useful Energy Produced)

	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste	Land Use	Thermal	Water Requirement	Occupational Health (per year)			
Scenarios	Part.	SO_2	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material	(10^3 tons/day)	(10^3 acres)	(Btu/hr)	(10^6 gal/day)	Deaths	Injuries	10^3 Man Days Lost	Overall Efficiency (%)
Natural Gas-fired	1,300	42	5,600	1,400	550	0	0	0	0	0	0	0	NA	NA	NA	60
Fuel Supply Scenario S11	90	280	1,500	98	140,000	0	0	0	0	28	0	0	1	130	21	95
Fuel Supply Scenario S12	1,900	18,000	17,000	2,800	580	0	0	0	14	48	0	42	15	1,300	83	65
Totals																
S11 Plus Water Heat End Use	1,400	320	9,000	1,500	140,000	0	0	0	0	28	0	0	1	130	21	57
S12 Plus Water Heat End Use	3,200	18,000	23,000	3,200	1,100	0	0	0	14	48	0	42	15	1,300	83	39
Oil-fired	5,400	23,000 (380)*	6,500	2,700	1,600	0	0	0	0	0	0	0	NA	NA	NA	55
Fuel Supply Scenario S8	790	2,000	4,000	1,200	5,800	0	17	.02	0	11	0	20	2.5	220	40	94
Fuel Supply Scenario S9	1,100	9,800	5,300	1,400	5,000	0	0	.02	300	11	0	38	2	340	NA	75
Fuel Supply Scenario S10	2,300	7,600	45,000	4,200	13,000	0	20	.1	19	87	0	96	20	1,800	98	52
Totals																
S8 Plus Water Heat End Use	6,200	25,000	11,000	4,000	7,400	0	17	.02	Neg	11	0	20	2.5	220	40	52
S9 Plus Water Heat End Use	6,500	10,000	12,000	4,100	6,600	0	0	.02	290	11	0	38	2	340	NA	41
S10 Plus Water Heat End Use	7,900	31,000	52,000	6,900	15,000	0	20	.1	19	87	0	96	20	1,800	98	29
Electric	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	42
Totals																
S1 Plus Water Heat End Use	2,000	560	80,000	2,300	240,000	3	17	1	0	51	0	130	.4	240	62	32
S2 Plus Water Heat End Use	1,300	27,000	97,000	4,400	12,000	4	47	1	11	27	0	180	5	400	77	30
S3 Plus Water Heat End Use	11,000	81,000	110,000	8,600	2,200	3	18	1	61	71	0	140	16	1,500	76	31
S4 Plus Water Heat End Use	11,000	140,000	120,000	18,000	3,900	3	17	1	10	55	0	130	5	370	28	31
S5 Plus Water Heat End Use	2,200	71,000	82,000	4,300	690	3	17	1	26	23	0	160	27	1,900	110	28
S6 Plus Water Heat End Use	6,600	46,000	110,000	8,400	2,100	3	18	1	70	30	0	150	21	1,900	130	26
S7 Plus Water Heat End Use	11,000	36,000	110,000	8,700	2,200	4	76	2	57	76	0	240	17	1,600	80	26

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†Fuel supply scenarios are burdened by end use efficiencies.

*Combustion of .005 wt. % S fuel oil produced by fuel supply scenario S9.

NA : Not Available

TABLE 5-7

ENVIRONMENTAL IMPACTS OF RESIDENTIAL COOKING END USE†

(Basis: 10^{12} Btu/Day of Useful Energy Produced)

Scenario	Air Emissions (lb/hr) Part.	SO_2	NO_x	CO	HC	Water Emissions (10^3 lb/hr) Suspended Solids	Dissolved Solids	Organic Material	Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Thermal (Btu/hr)	Water Requirement (10^6 gal/day)	Occupational Health (per year) Deaths	Injuries	10^3 Man Days Lost	Overall Efficiency (%)
Natural Gas-Fired	2,100	68	9,000	2,300	900	0	0	0	0	0	0	0	NA	NA	NA	37
Fuel Supply Scenario S11	140	450	5,600	160	220,000	0	0	0	0	46	0	0	2	210	15	95
Fuel Supply Scenario S12	3,000	29,000	27,000	4,600	940	0	0	0	21	78	0	68	24	2,100	130	65
Totals																
S11 Plus Cooking End Use	2,200	520	15,000	2,400	220,000	0	0	0	0	46	0	0	2	210	15	35
S12 Plus Cooking End Use	5,100	29,000	36,000	6,900	1,800	0	0	0	21	78	0	68	24	2,100	130	24
Oil-Fired	8,000	15,000 (570)*	9,700	4,700	2,400	0	0	0	0	0	0	0	NA	NA	NA	37
Fuel Supply Scenario S8	1,200	3,000	6,000	1,100	8,600	0	25	.03	0	20	0	30	3.8	120	59	95
Fuel Supply Scenario S9	1,600	15,000	7,800	1,900	7,400	0	0	.03	440	16	0	57	7	500	1	75
Fuel Supply Scenario S10	3,800	11,000	68,000	6,200	20,000	1	30	.16	28	130	0	160	10	2,700	150	52
Totals																
S8 Plus Cooking End Use	9,200	17,000	16,000	5,800	10,000	0	25	.03	0	20	0	30	10	120	59	35
S9 Plus Cooking End Use	9,600	16,000	18,000	5,900	9,800	0	0	.03	440	16	0	57	2.7	500	1	28
S10 Plus Cooking End Use	12,000	45,000	78,000	10,000	22,000	1	30	.16	26	130	0	160	28	2,700	150	19
Electric	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	75
Totals																
S1 Plus Cooking End Use	2,500	690	99,000	2,300	290,000	4	21	2	0	65	0	160	.4	290	52	26
S2 Plus Cooking End Use	1,600	33,000	120,000	5,400	15,000	5	57	2	13	33	0	220	5.9	580	95	25
S3 Plus Cooking End Use	13,000	100,000	140,000	11,000	2,700	4	23	2	75	88	0	190	20	1,600	93	26
S4 Plus Cooking End Use	13,000	170,000	150,000	21,000	4,800	4	21	1	15	120	0	160	7.7	510	58	26
S5 Plus Cooking End Use	2,900	87,000	100,000	6,800	1,000	4	21	2	29	99	0	200	27	2,300	130	22
S6 Plus Cooking End Use	8,100	56,000	130,000	19,000	2,600	4	23	2	86	99	0	190	28	2,700	150	21
S7 Plus Cooking End Use	14,000	44,000	140,000	11,000	2,700	4	94	2	64	91	0	290	21	2,000	99	21

†Fuel supply scenarios are burdened by end use efficiencies.
*Combustion of .30% wt S fuel oil produced by fuel supply scenario S9.

NA - Not Available.

TABLE 5-8

ENVIRONMENTAL IMPACTS OF COMMERCIAL SPACE HEAT END USE+

(Basis: 10^{12} Btu/Day of Useful Energy Produced)

Scenarios	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Thermal (Btu/hr)	Water Requirements (10^6 gal/day)	Occupational Health (per year)			Overall Efficiency (%)
	Part.	SO_x	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material					Deaths	Injuries	10^3 Man Days Lost	
Natural Gas-fired	1,000	32	6,500	1,100	430	0	0	0	0	0	0	0	NA	NA	NA	77
Fuel Supply Scenario S11	68	220	2,700	77	110,000	0	0	0	0	22	0	0	1.1	100	17	95
Fuel Supply Scenario S12	1,400	14,000	13,000	2,200	450	0	0	0	11	38	0	32	12	1,000	65	65
Totals																
S11 Plus Space Heat End Use	1,100	250	9,200	1,200	110,000	0	0	0	0	22	0	0	1.1	100	17	73
S12 Plus Space Heat End Use	2,400	14,000	20,000	3,300	880	0	0	0	11	38	0	32	12	1,000	65	50
Oil-Fired	5,900	17,000 (280)*	24 000	1,600	1,100	0	0	0	0	0	0	0	NA	NA	NA	76
Fuel Supply Scenario S8	570	1,400	2,900	880	4,200	0	12	.01	0	10	0	15	1.8	160	29	94
Fuel Supply Scenario S9	760	7,000	3,800	920	3,600	0	0	.01	220	8	0	28	3.6	240	NA	75
Fuel Supply Scenario S10	1,800	5,500	33,000	4,000	9,600		14	.08	14	63	0	70	14	1,300	71	52
Totals																
S8 Plus Space Heat End Use	6,500	18,000	26,000	2,500	5,300	0	12	.01	0	10	0	15	1.8	160	29	71
S9 Plus Space Heat End Use	6,700	7,400	27,000	2,500	4,800	0	0	.01	220	8	0	28	3.6	240	NA	57
S10 Plus Space Heat End Use	7,700	22,000	57,000	4,600	11,000	0	14	.08	14	63	0	70	14	1,300	71	40
Electric (Excluding Heat Pump)	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	100
Totals																
S1 Plus Space Heat End Use	1,800	520	74,000	2,100	220,000	3	16	1	0	49	0	120	.3	220	39	35
S2 Plus Space Heat End Use	1,200	25,000	89,000	4,100	11,000	4	43	1	10	25	0	160	4	360	71	33
S3 Plus Space Heat End Use	4,900	75,000	100,000	7,900	2,000	3	17	1	56	66	0	130	15	1,400	70	34
S4 Plus Space Heat End Use	10,000	120,000	110,000	17,000	3,600	3	16	1	11	87	0	120	.8	380	36	34
S5 Plus Space Heat End Use	2,200	65,000	78,000	5,100	740	3	16	1	22	74	0	150	20	1,700	100	30
S6 Plus Space Heat End Use	6,100	42,000	98,000	7,700	2,000	3	17	1	64	74	0	140	21	1,700	110	28
S7 Plus Space Heat End Use	10,000	33,000	100,000	8,000	2,100	3	70	1	48	70	0	220	16	1,500	74	30
Electric (Utilizing Heat Pump)	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	200
Totals																
S1 Plus Space Heat End Use	910	260	37,000	1,000	110,000	1	8	1	0	24	0	58	.2	110	20	70
S2 Plus Space Heat End Use	640	12,000	45,000	2,000	5,700	2	21	1	5	11	0	82	2	180	35	66
S3 Plus Space Heat End Use	4,900	37,000	51,000	3,900	1,000	2	8	1	28	33	0	66	7	680	35	68
S4 Plus Space Heat End Use	5,000	62,000	55,000	8,000	1,800	1	8	1	5	41	0	58	2.9	190	18	68
S5 Plus Space Heat End Use	1,100	33,000	39,000	2,600	370	1	8	1	11	37	0	75	16	850	50	60
S6 Plus Space Heat End Use	3,000	21,000	49,000	3,800	980	2	8	1	32	37	0	70	10	830	56	56
S7 Plus Space Heat End Use	5,100	17,000	52,000	4,000	1,000	2	35	1	24	35	0	110	8	740	37	60

+Fuel supply scenarios are burdened by end use efficiencies.
*Combustion of .005 wt % S fuel oil produced by fuel supply scenario S9.

NA - Not Available

TABLE 5-9

ENVIRONMENTAL IMPACTS OF COMMERCIAL WATER HEAT END USE*

(Basis: 10^{12} Btu/Day of Useful Energy Produced)

Scenarios	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Thermal (Btu/hr)	Water Requirements (10^6 gal/day)	Occupational Health (per year)			Overall Efficiency (%)
	Part.	SO_2	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material					Deaths	Injuries	10^3 Man Days Lost	
Natural Gas-Fired	1,300	42	8,300	1,400	550	0	0	0	0	0	0	0	NA	NA	NA	60
Fuel Supply Scenario S11	90	280	3,500	98	140,000	0	0	0	0	28	0	0	1	130	71	95
Fuel Supply Scenario S12	1,900	18,000	17,000	2,800	580	0	0	0	14	43	0	42	15	1,300	81	65
Totals																
S11 Plus Water Heat End Use	1,400	320	12,000	1,500	140,000	0	0	0	0	28	0	0	1	130	21	57
S12 Plus Water Heat End Use	3,200	18,000	25,000	4,000	1,100	0	0	0	15	58	0	42	15	1,300	83	39
Electric	0	0	0	0	0		0	0	0	0	0	0	NA	NA	NA	92
Totals																
S1 Plus Water Heat End Use	2,000	560	80,000	2,300	240,000	3	17	1	0	53	0	130	.4	240	42	32
S2 Plus Water Heat End Use	1,300	27,000	97,000	4,400	12,000	4	47	2	11	27	0	180	5	400	77	30
S3 Plus Water Heat End Use	11,000	81,000	110,000	8,600	2,200	3	18	1	61	71	0	140	16	1,500	76	31
S4 Plus Water Heat End Use	11,000	140,000	120,000	18,000	3,900	3	17	1	10	55	0	130	5	370	28	34
S5 Plus Water Heat End Use	2,200	71,000	82,000	4,900	690	3	17	1	24	80	0	160	22	1,900	110	28
S6 Plus Water Heat End Use	6,600	46,000	110,000	8,400	2,100	3	18	1	70	80	0	150	23	1,500	130	26
S7 Plus Water Heat End Use	11,000	36,000	110,000	8,700	2,200	4	76	2	52	76	0	250	17	1,600	80	28

*Fuel supply scenarios are burdened by end use efficiencies.

NA - Not Available

TABLE 5-10
ENVIRONMENTAL IMPACTS OF INDUSTRIAL SPACE HEAT END USE†

(Basis: 10^{12} Btu/day useful energy produced)

Scenarios	Air Emissions (lb/hr) Part.	SO_x	NO_x	CO	HC	Water Emissions (10^3 lb/hr) Suspended Solids	Dissolved Solids	Organic Material	Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Thermal (Btu/hr)	Water Requirements (10^6 gal/day)	Occupational Health (per year) Deaths	Injuries	10^3 Man-Days Lost	Overall Efficiency (%)
Natural Gas-Fired	1,000	32	6,500	1,100	430	0	0	0	0	0	0	0	NA	NA	NA	77
Fuel Supply Scenario S11	68	220	2,700	77	110,000	0	0	0	0	22	0	0	1.1	100	17	95
Fuel Supply Scenario S12	1,400	14,000	13,000	2,200	450	0	0	0	11	38	0	12	12	1,000	65	65
Totals																
S11 Plus Space Heat End Use	1,100	250	9,200	1,200	110,000	0	0	0	0	22	0	0	1.1	100	17	73
S12 Plus Space Heat End Use	2,400	14,000	20,000	3,300	880	0	0	0	11	38	0	12	12	1,100	65	50
Oil-Fired	5,900	17,000 (780)*	24,000	1,600	1,100	0	0	0	0	0	0	0	NA	NA	NA	76
Fuel Supply Scenario S8	570	1,600	2,900	880	4,200	0	12	.01	0	10	0	15	1.8	160	29	94
Fuel Supply Scenario S9	760	7,000	3,800	920	3,600	0	0	.01	220	8	0	28	3.6	240	NA	75
Fuel Supply Scenario S10	1,300	5,500	33,000	3,600	9,600	0	14	.08	14	61	0	70	14	1,300	71	52
Totals																
S8 Plus Space Heat End Use	6,500	18,000	26,000	2,500	5,300	0	12	.01	0	10	0	15	1.8	160	29	71
S9 Plus Space Heat End Use	6,700	7,400	27,000	2,500	5,800	0	0	.01	220	8	0	28	3.6	240	NA	[illegible]
S10 Plus Space Heat End Use	7,700	22,000	57,000	4,600	11,000	0	14	.08	14	61	0	70	14	1,300	71	50
Electric (Excluding Heat Pump)	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	95
Totals																
S1 Plus Space Heat End Use	1,900	540	77,000	2,200	230,000	1	17	1	0	32	0	120	4	230	41	33
S2 Plus Space Heat End Use	1,300	26,000	94,000	4,300	12,000	4	45	2	10	26	0	170	5	380	53	31
S3 Plus Space Heat End Use	10,000	79,000	110,000	8,300	2,100	3	18	1	30	69	0	140	16	1,400	75	32
S4 Plus Space Heat End Use	11,000	130,000	120,000	18,000	3,200	3	17	1	12	92	0	120	6	400	38	32
S5 Plus Space Heat End Use	7,300	69,000	80,000	5,300	780	3	17	1	21	78	0	150	21	1,800	110	28
S6 Plus Space Heat End Use	6,300	44,000	100,000	8,100	7,100	3	18	1	68	78	0	150	22	1,800	120	27
S7 Plus Space Heat End Use	11,000	35,000	110,000	8,400	2,200	4	74	1	50	74	0	230	17	1,600	78	29
Electric (Utilizing Heat Pump)	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	190
Totals																
S1 Plus Space Heat End Use	950	270		1,100	120,000	1	8	1	0	26	0	60	2	120	20	66
S2 Plus Space Heat End Use	700	13,000	47,000	2,100	6,000	2	23	1	5	13	0	86	2	190	43	62
S3 Plus Space Heat End Use	5,000	19,000	54,000	4,100	1,100	2	9	1	29	35	0	69	8	710	37	64
S4 Plus Space Heat End Use	5,000	66,000	60,000	8,500	1,900	2	8	1	6	40	0	61	3	200	19	64
S5 Plus Space Heat End Use	1,100	34,000	41,000	2,400	390	1	8	1	12	39	[illegible]	75	10	900	55	56
S6 Plus Space Heat End Use	3,200	22,000	51,000	7,300	1,000	2	9	1	14	39	0	74	11	880	60	54
S7 Plus Space Heat End Use	5,400	17,000	55,000	4,000	1,100	2	37	1	25	37	0	114	8	780	39	58

†Fuel supply scenarios are burdened by end use efficiencies.
*Combustion of .095 wt. % S fuel oil produced by fuel supply scenario S9.

NA - Not Available

TABLE 5-11
ENVIRONMENTAL IMPACTS OF INDUSTRIAL COOKING USE*
(Basis: 10^{12} Btu/Day of Useful Energy Produced)

	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste	Land Use	Thermal	Water Requirement	Occupational Health (per year)			Overall
Scenario	Part.	SO_2	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material	(10^3 tons/day)	(10^3 acres)	(Btu/hr)	(10^6 gal/day)	Deaths	Injuries	10^3 Man Day Lost	Efficiency (%)
Natural Gas Fired	2,000	70	14,000	1,900	140	0	0	0	0	0	0	0	NA	NA	NA	37
Fuel Supply Scenario S11	160	450	5,600	160	220,000	0	0	0	0	46	0	0	2	210	15	56
Fuel Supply Scenario S12	3,000	29,000	27,000	4,600	950	0	0	0	23	78	0	68	23	2,100	130	55
Totals:																
S11 Plus Cooking End Use	2,200	520	20,000	2,100	220,000	0	0	0	0	46	0	0	2	210	15	35
S12 Plus Cooking End Use	5,100	29,000	41,000	6,500	1,300	0	0	0	23	78	0	68	23	2,100	130	[illegible]
Electric	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	25
Totals:																
S1 Plus Cooking End Use	2,400	690	99,000	2,800	290,000	4	21	2	0	63	0	150	5	290	52	26
S2 Plus Cooking End Use	1,600	11,000	120,000	5,400	15,000	5	57	2	13	11	0	224	6	480	95	25
S3 Plus Cooking End Use	13,000	140,000	140,000	11,000	2,700	4	23	2	75	58	0	180	20	1,800	91	26
S4 Plus Cooking End Use	13,000	170,000	150,000	21,000	6,800	4	21	1	15	120	0	160	8	510	58	26
S5 Plus Cooking End Use	5,900	87,000	100,000	6,800	990	4	21	2	20	81	0	300	27	2,900	130	22
S6 Plus Cooking End Use	7,100	56,000	130,000	10,000	2,600	4	23	2	86	99	0	190	26	2,200	150	21
S7 Plus Cooking End Use	13,000	66,000	140,000	11,000	2,700	4	94	2	65	93	0	290	21	2,000	99	23

*Fuel supply scenarios are backed by end use efficiencies.

NA - Not Available

TABLE 5-12

ENVIRONMENTAL IMPACTS OF INDUSTRIAL HEATING AND ANNEALING END USE†

(Basis: 10^{12} Btu/Day of Useful Energy Produced)

	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste	Land Use	Thermal	Water Requirement	Occupational Health (per year)			
Scenarios	Part.	SO_x	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material	(10^3 tons/day)	(10^3 acres)	(Btu/hr)	(10^6 gal/day)	Deaths	Injuries	10^3 Man Days Lost	Overall Efficiency (%)
Natural Gas-Fired	6,800	230	87,000	6,400	1,100	0	0	0	0	0	0	0	NA	NA	NA	11
Fuel Supply Scenario S11	470	1,500	19,000	540	740,000	0	0	0	0	150	0	0	7	700	120	95
Fuel Supply Scenario S12	10,000	98,000	92,000	15,000	3,200	0	0	0	79	260	0	230	81	7,100	450	65
Totals																
S11 Plus Heating and Annealing End Use	7,300	1,700	110,000	7,000	740,000	0	0	0	0	150	0	0	7	730	120	10
S12 Plus Heating and Annealing End Use	17,000	98,000	180,000	21,000	4,300	0	0	0	79	260	0	230	81	7,100	450	7
Oil-Fired	41,000	120,000 (1,900)*	160,000	11,000	8,100	0	0	0	0	0	0	0	NA	NA	NA	11
Fuel Supply Scenario S8	3,900	10,000	20,000	6,100	29,000	2	83	.09	0	66	0	100	13	1,100	200	94
Fuel Supply Scenario S9	5,300	49,000	26,000	6,400	25,000	0	0	.09	1,500	55	0	190	25	1,700	3	75
Fuel Supply Scenario S10	13,000	38,000	230,000	21,000	66,000	3	100	.55	94	440	0	480	100	9,000	590	52
Totals																
S8 Plus Heating and Annealing End Use	45,000	130,000	180,000	17,000	37,000	2	83	.09	0	66	0	100	13	1,100	200	10
S9 Plus Heating and Annealing End Use	46,000	51,000	190,000	17,000	33,000	0	0	.09	1,500	55	0	190	25	1,700	3	8
S10 Plus Heating and Annealing End Use	54,000	160,000	390,000	32,000	74,000	3	100	.55	94	440	0	480	100	9,000	590	6
Electric	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	[illegible]
Totals																
S1 Plus Heating and Annealing End Use	1,900	540	78,000	2,200	230,000	3	17	1	0	52	0	120	.4	230	43	33
S2 Plus Heating and Annealing End Use	1,300	26,000	94,000	4,300	12,000	4	45	2	10	26	0	170	5	180	75	31
S3 Plus Heating and Annealing End Use	10,000	79,000	110,000	8,300	2,000	[illegible]	18	1	59	69	0	140	16	1,400	75	32
S4 Plus Heating and Annealing End Use	11,000	130,000	120,000	18,000	3,800	3	17	1	12	32	0	120	6	400	38	32
S5 Plus Heating and Annealing End Use	2,100	69,000	82,000	5,400	790	3	17	1	23	78	0	150	21	1,800	110	28
S6 Plus Heating and Annealing End Use	6,500	44,000	100,000	8,100	2,100	3	18	1	68	78	0	150	22	1,800	120	27
S7 Plus Heating and Annealing End Use	11,000	35,000	110,000	8,400	2,200	4	74	1	30	74	0	230	17	1,600	73	29

†Fuel supply scenarios are burdened by end use efficiencies.

*Combustion of 0.3% wt. S fuel oil produced by fuel supply scenario S9.

NA = Not Available

TABLE 5.13

ENVIRONMENTAL IMPACTS OF INDUSTRIAL STEEL MAKING END USE[1]

(Basis: 10^{12} Btu/Day of Useful Energy Produced)

Scenario	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste (10^3 tons/day)	Land Use (10^3 acres)	Thermal (Btu/hr)	Water Requirement (10^6 gal/day)	Occupational Health (per year)			Overall Efficiency (%)
	Part.	SO_x	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material					Deaths	Injuries	10^3 Man Days Lost	
Natural Gas-fired	1,800	60	23,000	1,700	300	0	0	0	0	0	0	0	NA	NA	NA	42
Fuel Supply Scenario S11	120	400	5,000	140	190,000	0	0	0	0	40	0	0	2	180	31	97
Fuel Supply Scenario S12	2,700	26,000	24,000	4,000	830	0	0	0	21	69	0	60	21	1,900	120	65
Totals																
S11 Plus Steel Making End Use	1,900	460	28,000	1,800	190,000	0	0	0	0	40	0	0	2	190	31	41
S12 Plus Steel Making End Use	4,500	26,000	47,000	5,700	1,100	0	0	0	21	69	0	60	21	1,900	120	27
Oil-fired	11,000	30,000 (500)*	43,000	2,800	2,100	0	0	0	0	0	0	0	NA	NA	NA	42
Fuel Supply Scenario S8	1,000	2,600	5,200	1,600	7,600	0	22	.02	0	17	0	230	3.3	280	52	94
Fuel Supply Scenario S9	1,400	13,000	6,900	1,700	6,500	0	0	.02	390	14	0	50	7	440	1	75
Fuel Supply Scenario S10	3,300	10,000	60,000	5,500	17,000	0	26	.14	25	110	0	130	26	2,400	130	52
Totals																
S8 Plus Steel Making End Use	12,000	33,000	48,000	4,400	9,700	0	22	.02	0	17	0	230	3.3	280	52	39
S9 Plus Steel Making End Use	12,000	13,000	50,000	4,500	8,600	0	0	.02	390	14	0	50	7	440	1	32
S10 Plus Steel Making End Use	14,000	41,000	100,000	8,300	19,000	0	26	.14	25	110	0	130	26	2,400	130	22
Electric	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	95
Totals																
S1 Plus Steel Making End Use	1,900	540	78,000	2,200	230,000	3	17	1	0	52	0	120	[illegible]	230	51	33
S2 Plus Steel Making End Use	1,300	26,000	94,000	4,300	12,000	4	45	2	16	26	0	170	5	380	75	31
S3 Plus Steel Making End Use	10,000	79,000	110,000	8,300	2,100	3	18	1	59	69	0	140	16	1,400	75	32
S4 Plus Steel Making End Use	11,000	130,000	120,000	18,000	3,800	3	17	1	12	92	0	120	6	480	36	32
S5 Plus Steel Making End Use	7,300	69,000	82,000	5,400	780	3	17	1	23	78	0	150	21	1,800	110	28
S6 Plus Steel Making End Use	6,500	44,000	100,000	8,100	2,100	3	18	1	68	78	0	150	22	1,800	120	27
S7 Plus Steel Making End Use	11,000	35,000	110,000	8,400	2,200	4	74	1	50	74	0	230	17	1,600	78	29

[1] Fuel supply scenarios are burdened by end use efficiencies.

*Combustion of .30% wt. S fuel oil produced by fuel supply scenario S9.

NA = Not Available

TABLE 5-14

ENVIRONMENTAL IMPACTS OF INDUSTRIAL GLASS MELTING END USE†

(Basis: 10^{12} Btu/Day of Useful Energy Produced)

	Air Emissions (lb/hr)					Water Emissions (10^3 lb/hr)			Solid Waste	Land Use	Thermal	Water Requirement	Occupational Health (per year)			
Scenarios	Part.	SO_2	NO_x	CO	HC	Suspended Solids	Dissolved Solids	Organic Material	(10^3 tons/day)	(10^3 acres)	(Btu/hr)	(10^6 gal/day)	Deaths	Injuries	10^3 Man Days Lost	Overall Efficiency (%)
Natural Gas Fired	4,400	150	57,000	4,200	740	0	0	0	0	0	0	0	NA	NA	NA	17
Fuel Supply Scenario S11	310	1,000	12,000	350	480,000	0	0	0	0	99	0	0	5	470	75	94
Fuel Supply Scenario S12	6,600	64,000	59,000	10,000	2,100	0	0	0	51	170	0	150	52	4,600	290	66
Totals																
S11 Plus Glass Melting End Use	4,700	1,100	69,000	4,500	480,000	0	0	0	0	99	0	0	5	NA	75	15
S12 Plus Glass Melting End Use	11,000	64,000	120,000	13,000	2,800	0	0	0	51	170	0	150	52	4,600	290	11
Electric	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	95
Totals																
S1 Plus Glass Melting End Use	1,900	560	78,000	2,200	210,000	3	27	1	0	17	0	120	4	230	31	11
S2 Plus Glass Melting End Use	1,300	26,000	95,000	4,300	12,000	4	45	2	10	26	0	170	5	180	21	11
S3 Plus Glass Melting End Use	10,000	79,000	110,000	8,300	2,100	3	18	1	59	69	0	140	16	1,400	76	12
S4 Plus Glass Melting End Use	11,000	111,000	120,000	18,000	3,800	3	17	1	12	92	0	120	6	500	38	32
S5 Plus Glass Melting End Use	7,300	69,000	82,000	5,400	780	3	17	1	21	78	0	150	21	1,800	110	28
S6 Plus Glass Melting End Use	6,400	44,000	100,000	8,100	2,100	3	18	1	68	78	0	150	[illegible]	1,800	120	27
S7 Plus Glass Melting End Use	11,000	35,000	110,000	8,500	2,200	4	24	1	50	74	0	230	17	1,600	78	29

†Fuel supply scenarios are burdened by end use efficiencies.
NA - Not Available.

other hand differ significantly from the impacts calculated for each fuel supply scenario since

(1) emissions from the end use modules themselves are not insignificant, and

(2) fuel supply scenario impacts are burdened by a factor of 100/Efficiency (fossil fuel end use modules are considerably less than 100% energy efficient).

5.2.1 End Use Scenario Rankings Based Upon Energy Use Efficiency

Relative rankings of space heating end use scenarios according to their overall energy efficiencies were similar for all of the three sectors considered. For those cases which excluded heat pumps, fossil fuel end use scenarios generally proved to be the most energy efficient (see Tables 5-15, 5-17 and 5-20). This implies that, although the efficiencies of conventional electrical space heating equipment items are greater than those exhibited by their fossil fuel powered alternatives, this increase in efficiency is not sufficient to compensate for the low conversion efficiency of the power plant module used in electricity supply scenarios. A different situation exists when utilizing a heat pump for space heating in the residential sector since the high efficiency of this device more than compensates for the low efficiency of the electrical conversion step (see Table 5-16). Commercial and industrial space heating scenarios utilizing heat pumps for the electrical cases show mixed rankings (see Tables 5-18 and 5-21) since the increased efficiencies of fossil fuel equipment items balance somewhat the greater efficiency of the heat pump.

TABLE 5-15
RESIDENTIAL SPACE HEAT SCENARIO RANKING (EXCLUDING ELECTRIC HEAT PUMPS)

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	57
2	S8 - Fuel Oil	52
3	S9 - Fuel Oil	41
4	S12 - Natural Gas	39
5	S1 - Electricity	35
6	S4 - Electricity	34
7	S3 - Electricity	34
8	S2 - Electricity	33
9	S7 - Electricity	30
10	S5 - Electricity	30
11	S10 - Fuel Oil	29
12	S6 - Electricity	28

---

* See Table 5-2 for scenario modules.

TABLE 5-16

RESIDENTIAL SPACE HEAT SCENARIO RANKING

(UTILIZING HEAT PUMPS)

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S1 - Electricity	70
2	S4 - Electricity	68
3	S3 - Electricity	68
4	S2 - Electricity	66
5	S7 - Electricity	60
6	S5 - Electricity	60
7	S11 - Natural Gas	57
8	S6 - Electricity	56
9	S8 - Fuel Oil	52
10	S9 - Fuel Oil	41
11	S12 - Natural Gas	39
12	S10 - Fuel Oil	29

---

* See Table 5-2 for scenario modules.

TABLE 5-17

COMMERCIAL SPACE HEAT SCENARIO RANKING (EXCLUDING ELECTRIC HEAT PUMPS)

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	73
2	S8 - Fuel Oil	71
3	S9 - Fuel Oil	57
4	S12 - Natural Gas	50
5	S10 - Fuel Oil	40
6	S1 - Electricity	35
7	S4 - Electricity	34
8	S3 - Electricity	34
9	S2 - Electricity	33
10	S7 - Electricity	30
11	S5 - Electricity	30
12	S6 - Electricity	28

---

* See Table 5-2 for scenario modules.

TABLE 5-18

COMMERCIAL SPACE HEAT SCENARIO RANKING

(UTILIZING HEAT PUMPS)

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	73
2	S8 - Fuel Oil	71
3	S1 - Electricity	70
4	S4 - Electricity	68
5	S3 - Electricity	68
6	S2 - Electricity	66
7	S7 - Electricity	60
8	S5 - Eleectricity	60
9	S9 - Fuel Oil	57
10	S6 - Electricity	56
11	S12 - Natural Gas	50
12	S10 - Fuel Oil	40

---

* See Table 5-2 for scenario modules.

TABLE 5-19

COMMERCIAL WATER HEATING SCENARIO RANKING*

Rank	Fuel Supply Scenario Number** and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	57
2	S12 - Natural Gas	39
3	S1 - Electricity	32
4	S4 - Electricity	31
5	S3 - Electricity	31
6	S2 - Electricity	30
7	S7 - Electricity	28
8	S5 - Electricity	28
9	S6 - Electricity	26

---

* Fuel oil is not used for water heating to any significant extent.

** See Table 5-2 for scenario modules.

TABLE 5-20
INDUSTRIAL SPACE HEAT SCENARIO RANKING
(EXCLUDING HEAT PUMPS)

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	73
2	S8 - Fuel Oil	71
3	S9 - Fuel Oil	57
4	S12 - Natural Gas	50
5	S10 - Fuel Oil	40
6	S1 - Electricity	33
7	S4 - Electricity	32
8	S3 - Electricity	32
9	S2 - Electricity	31
10	S7 - Electricity	29
11	S5 - Electricity	28
12	S6 - Electricity	27

---

* See Table 5-2 for scenario modules.

TABLE 5-21

INDUSTRIAL SPACE HEAT SCENARIO RANKING (UTILIZING HEAT PUMPS)

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	73
2	S8 - Fuel Oil	71
3	S1 - Electricity	66
4	S4 - Electricity	64
5	S3 - Electricity	64
6	S2 - Electricity	62
7	S7 - Electricity	58
8	S9 - Fuel Oil	57
9	S5 - Electricity	56
10	S6 - Electricity	54
11	S12 - Natural Gas	50
12	S10 - Fuel Oil	40

---

* See Table 5-2 for scenario modules.

Commercial water heating is accomplished by using either natural gas-fired or electrical equipment. According to the data presented in Table 5-19, the natural gas case is always more efficient.

The remaining industrial sector end uses which are considered in Tables 5-22 through 5-25 are of less importance than the cases which were just discussed due to their limited potential for conversion. Some discussion of these industrial sector cases is appropriate however.

In the steel making industry (see Table 5-22) overall end use scenario efficiencies are very similar for the fossil fuel and electrical cases due to the low efficiencies exhibited by the fossil fuel powered equipment items dedicated to this end use. For the heating and annealing end use, electrical alternatives are considerably more attractive from an overall efficiency standpoint. This is also true in the industrial glass melting category. Fossil fuels, on the other hand, appear to be more attractive fuels than electricity for the industrial cooking case.

5.2.2 End Use Scenario Comparisons Based Upon Environmental Impacts

In the previous section, a total of eight significant end use applications in the residential, commercial and industrial sectors were compared on the basis of their overall energy use efficiencies. In this section, these same end uses are considered from an environmental impact point of view. The end use categories which are treated in greatest detail here are the residential and commercial space heat categories, since these categories are representative of end uses which account

TABLE 5-22

INDUSTRIAL STEEL MAKING SCENARIO RANKING

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	41
2	S8 - Fuel Oil	39
3	S1 - Electricity	33
4	S4 - Electricity	32
5	S3 - Electricity	32
6	S9 - Fuel Oil	32
7	S2 - Electricity	31
8	S7 - Electricity	29
9	S5 - Electricity	28
10	S12 - Natural Gas	27
11	S6 - Electricity	27
12	S10 - Fuel Oil	22

---

* See Table 5-2 for scenario modules.

TABLE 5-23

INDUSTRIAL HEATING AND ANNEALING SCENARIO RANKING

Rank	Fuel Supply Scenario Number* and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S1 - Electricity	33
2	S4 - Electricity	32
3	S3 - Electricity	32
4	S2 - Electricity	31
5	S7 - Electricity	29
6	S5 - Electricity	28
7	S6 - Electricity	27
8	S11 - Natural Gas	10
9	S8 - Fuel Oil	10
10	S9 - Fuel Oil	8
11	S12 - Natural Gas	7
12	S10 - Fuel Oil	6

---

* See Table 5-2 for scenario modules.

TABLE 5-24

INDUSTRIAL COOKING SCENARIO RANKING*

Rank	Fuel Supply Scenario Number** and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S11 - Natural Gas	35
2	S1 - Electricity	26
3	S4 - Electricity	26
4	S3 - Electricity	26
5	S2 - Electricity	25
6	S12 - Natural Gas	24
7	S7 - Electricity	23
8	S5 - Electricity	22
9	S6 - Electricity	21

---

* Fuel oil is not utilized in this end use.

** See Table 5-2 for scenario modules.

TABLE 5-25

INDUSTRIAL GLASS MELTING SCENARIO RANKING*

Rank	Fuel Supply Scenario Number** and End Use Energy Form	Overall End Use Scenario Efficiency (%)
1	S1 - Electricity	33
2	S4 - Electricity	32
3	S3 - Electricity	32
4	S2 - Electricity	31
5	S7 - Electricity	29
6	S5 - Electricity	28
7	S6 - Electricity	27
8	S11 - Natural Gas	15
9	S12 - Natural Gas	11

---

* Fuel oil is not utilized in this end use.

** See Table 5-2 for scenario modules.

for about 85% of the convertible fossil fuels currently consumed in the three sectors considered in this study.

5.2.2.1 Residential Space Heat End Use (Excluding Electric Heat Pumps)

Quantitatively, SO_2 and NO_x emissions are significantly greater than the other air emissions generated by residential space heat end use scenarios. Exceptions to this general rule occur in cases involving fuel supply scenarios S1 and S11. Hydrocarbon emissions for those cases are significant due to the wellhead losses which occur in the natural gas extraction module. Hydrocarbon emissions from other scenarios are generally insignificant.

Electrical space heat scenarios typically generate more SO_2 and NO_x than fossil fuel scenarios. This is particularly true in the case of NO_x emissions due to the contributions of power plant modules which generate significant quantities of NO_x regardless of the fuel which is consumed. Greater variations in SO_2 emissions are observed among the scenarios since these emissions are directly related to the sulfur content of the fuel burned. Since fuel sulfur content generally conforms to the following pattern: coal → fuel oil → natural gas, SO_2 emissions from end use scenarios follow a similar pattern.

Electrical end use scenarios all have significant water emissions. This is due to the quantity of cooling water blowdown required to support a cooling system capable of dissipating the waste heat generated by a power plant. End use scenarios using electrical energy produced in power plants which require flue gas desulfurization units also produce large quantities of solid waste. End uses requiring fuel oil generated in fuel supply scenario S9 generate large quantities of solid wastes due to the oil shale processing module. Coal conversion scenarios (S5, S10 and S12) generate relatively moderate quantities of solid wastes.

5.2.2.2 Residential Space Heat End Use (Utilizing Electric Heat Pumps)

With the application of electric heat pumps in residential space heat end use scenarios, the environmental impacts of electrical fuel supply scenarios are effectively reduced by 50%. Although this constitutes a significant reduction in the overall environmental impacts of these scenarios, it results in few meaningful changes in relative end use impact rankings. The most significant consequence of this higher end use efficiency appears to be the reduction of electrical end use SO_2 emissions to levels that are more in line with those of fossil fuel end use scenarios.

5.2.2.3 Commercial Space Heat

Commercial space heat end use scenarios differ from the residential space heat end use scenarios in two ways:

(1) the energy efficiencies of the fossil fuel powered equipment items used in the commercial sector are greater, and

(2) NO_x emissions per unit of fossil fuel energy consumed are greater.

The environmental impacts of commercial electric space heat scenarios are identical to those calculated for the residential sector.

As a result of these differences in commercial and residential space heating equipment, overall impacts of fossil fuel scenarios in the commercial sector are reduced (relative to the residential case) except for NO_x emissions, which are increased. This causes no significant change, however, in the relative rankings of space heat scenarios based upon their impacts. The decreases in air emissions which occur in the fossil fuel cases, only serve to increase the gaps between electric and fossil fuel end use scenario impacts. The increased NO_x emissions which are realized bring fossil fuel NO_x emission levels closer to those of electrical end uses; however, electrical end use NO_x emissions are still generally higher.

5.2.2.4 Other End Uses

Relative impacts of other significant end uses considered in this study follow the same general patterns which were discussed above for the residential and commercial space heating cases. For this reason, specific consideration of each significant end use case defined in the impact summary tables was not attempted.

6.0 DEFINITION OF AMBIENT AIR IMPACT OF ELECTRICAL CONVERSION

This section presents both the method used to estimate the ambient air impact in a metropolitan area of converting as many uses of fossil fuels to electricity as possible and the results of that ambient air impact assessment. The area modeled in this study was the Chicago Air Quality Control Region (AQCR). The ambient air impact was determined by calculating ambient air concentrations of SO_2, NO_x, CO, hydrocarbons, and particulates for the present time and for the years 1985 and 2000 for two cases:

Case I - The usage of electricity versus fossil fuels in the residential, commercial and industrial sectors remains in the same proportion as it is today (i.e., usage of electricity and usage of fossil fuels grow at the same rate).

Case II - All future installations in the residential, commercial and industrial sectors which can use electricity, do install electrical equipment instead of fossil-fuel-fired equipment. Existing fossil-fired equipment in those sectors is replaced by electrical equipment, where possible, when the existing units are retired.

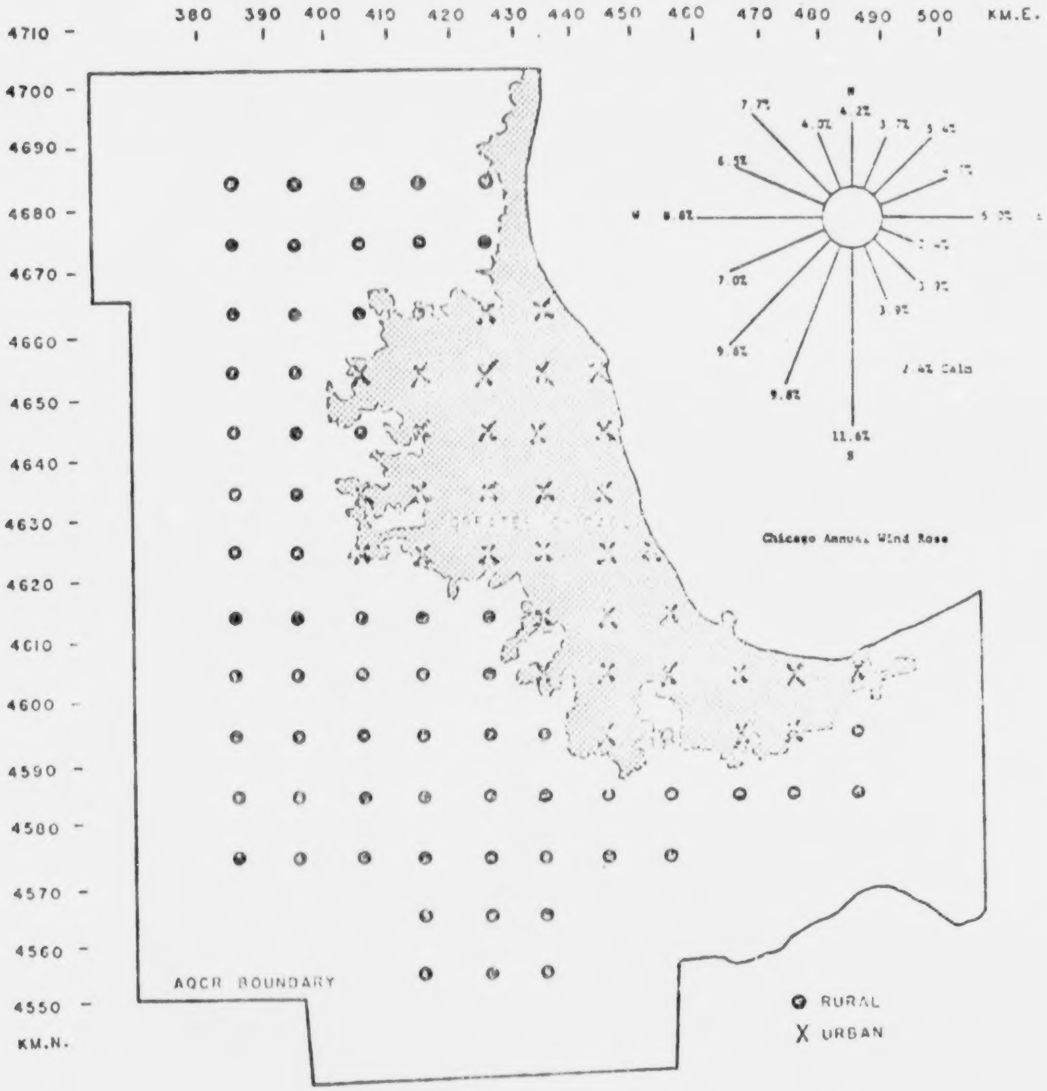
In each case, the increased electrical usage in future years was assumed to be provided by new or expanded central power stations at projected sites within the AQCR, but remote from population centers. These power stations were assumed to burn coal and to employ suitable control technology to meet Federal new source emission standards.

. The ambient air concentrations used in this study are geographic averages of the annual averages computed at the receptors shown in Figure 6-1. Two geographic averages are reported: (1) an average over the urban receptors, and (2) an average over the rural receptors. Thus, for each case in each year two sets of average concentrations for the five pollutants are given - the urban geographic average set (hereafter called "urban"), and the rural geographic average set (hereafter called "rural").

The benefits of using this scheme are numerous. The most notable ones are that it reduces an unmanageable set of numbers to a manageable set while maintaining the essential information, and it allows the use of the efficient and flexible concentration projection approach discussed below.

6.1 Methodology

The annual average ambient air concentrations of the five pollutants for the years 1974, 1985 and 2000 were projected from dispersion model runs using 1970 National Emissions Data System (NEDS) data for the Chicago AQCR, and projected power plant emissions. These projections were made by computing the present and future year ambient air concentrations produced by increased area source and point source emissions using influence coefficients derived from dispersion modeling of the 1970 NEDS emissions for the Chicago AQCR.


380
390
400
410
420
430
440
450
460
470
480
490
500
KM.E.
4710
4700
4690
4680
4670
4660
4650
4640
4630
4620
4610
4600
4590
4580
4570
4560
4550
KM.N.
GREATER CHICAGO
AQCR BOUNDARY
N
7.7%
6.2%
4.3%
3.7%
6.5%
W
8.8%
7.0%
9.8%
9.8%
11.6%
S
3.9%
Calm
Chicago Annual Wind Rose
RURAL
X URBAN

RECEPTOR GRID FOR CHICAGO

FIGURE 6-1

This type of approach was selected because of the extensive savings in computer time over that required for direct dispersion modeling of all cases, as well as, for its flexibility. The flexibility is inherent because new emission sources do not need to be sited specifically or completely defined. Thus this approach is well suited to the task of predicting the future air impact of electricity substitution.

The flexibility of this approach makes it possible to assess the effect of changing geographic growth patterns on the air impact of electricity substitution. To study this effect, two extremes of geographic growth are utilized in this study. These two extremes bound the future air impact of electricity substitution with a relatively high degree of confidence. The two extremes are:

Type 1 Growth - essentially no geographic growth in emissions sources (i.e., the urban and industrial areas do not grow in size, but energy usage, and thus emissions, increase).

Type 2 Growth - extensive geographic growth in emissions sources (i.e., all growth in energy usage is on the outskirts of the existing urban area, large new industrial sources are located in remote rural areas in the AQCR).

Type 1 growth would tend to occur if transportation becomes a problem due to energy shortages, while Type 2 growth would occur where urban ambient air quality is the primary concern. However, the actual growth pattern will probably lie somewhere between the two.

The detailed procedures used to institute the general approach discussed above will now be addressed.

6.1.1 Energy Use Projections

The 1974 estimated energy demand pattern for the residential, commercial and industrial sectors of the Chicago AQCR is shown in Table 6-1. The data in this table were gathered from several sources (US-074, FE-035, NA-148, EL-063, ST-186, NA-200), many of which contained data for a year other than 1974. When data for years other than 1974 were used, they were projected to 1974 using the 1960-68 annual average energy growth rates for the United States.

6.1.1.1 Case I - Electricity Usage

The growth in energy demand of the Chicago AQCR is assumed to be at the same average annual rates as that for the nation as a whole. The growth rates are thus computed from the projected national energy use patterns in Section 3.0 (Tables 3-5, 3-6 and 3-7). In keeping with the definition of Case I, the growth rates for electricity and fossil fuels are assumed to be the same so that the relative proportions of electricity and fossil fuel use remain the same in future years. Separate growth rates are used for the residential, commercial, and industrial sector. Each of these growth rates is computed from the total energy use of the corresponding sector. Different growth rates are computed for the 1972-1985 period and the 1972-2000 period. The resulting energy demand projections are shown in Table 6-2.

TABLE 6-1

ESTIMATED 1974 ENERGY DEMAND PATTERN FOR CHICAGO AQCR

Sector, fuel	Annual Energy Usage (10^{12} Btu)
Residential,	
coal	9
oil	175
gas	406
total fossil	590
electricity*	62
Commercial,	
coal	1
oil	79
gas	139
total fossil	219
electricity*	88
Industrial,	
coal	111
oil	96
gas	352
total fossil	559
electricity*	84

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*electricity converted at 3,413 Btu/kwhr

TABLE 6-2
ESTIMATED FUTURE ENERGY DEMAND FOR CHICAGO AQCR, CASE I

Sector, fuel	Annual Energy Usage (10^{12} Btu) 1985	2000
Residential,		
coal	12	17
oil	233	333
gas	541	773
total fossil	786	1,123
electricity*	83	118
Commercial,		
coal	2	2
oil	123	179
gas	216	314
total fossil	341	495
electricity*	137	199
Industrial,		
coal	158	261
oil	136	226
gas	500	827
total fossil	794	1,314
electricity*	119	197

---

*electricity converted at 3,413 Btu/kwhr

6.1.1.2 Case II Electricity Usage

The 1985 and 2000 energy demand patterns for the Chicago AQCR under the Case II electricity usage assumptions are computed from the corresponding Case I energy demand patterns. This computation is performed in three steps - (1) the switchable amount of the growth in fossil fuel usage from 1974 levels is computed, (2) the amount of 1974 fossil fuel usage that is converted through replacement of retired units is computed, and (3) the amount of substitute electric energy required to satisfy the switched demand is computed. The residential and commercial sectors are treated together due to their similarity and the industrial sector is treated separately. It is assumed in this section that the energy end use (eg., space heating, water heating, etc.) patterns in the Chicago AQCR are the same as the national average patterns reported in Appendicies A and B.

Step 1 - Table 3-11 indicates that in 1985 and in 2000, 100% of the residential fossil fuel use is convertible to electricity while 83% of the commercial fossil fuel use is convertible. Since the percentages are essentially the same as in 1974, they may be applied to the growth in fossil fuel usage from 1974 to 1985 or 2000. This indicates that in 1985, 296 x 10^{12} Btu of residential and commercial fossil fuel use may be converted while in 2000, 763 x 10^{12} Btu may be converted.

The industrial fossil fuel usage indicated in Table 3-11 as switchable ranges from 18% to 22%. However, this was qualified as being a possible upper bound if equipment were available. As shown in Appendix B, a more realistic number for national industrial convertibility in 1968 is 1,679 x 10^{12} Btu. Since the total industrial fossil fuel usage in 1968 was 19,438 x 10^{12} Btu, this means only 8.6% is convertible.

Assuming this percentage to apply for future years, yields 20×10^{12} Btu convertible in 1985, and 66×10^{12} Btu, in 2000.

Step 2 - From Table 3-5 the following end use percentages of the switchable fossil fuel use in the residential and commercial sectors in 1972 are computed.

space heat - 82%
water heat - 13%
cooking - 4%
other - 1%

From Section 7.0 the average lifetimes of fossil fired equipment are:

space heater - 15 years
water heater - 12 years
cook stove - 17 years
other - ∿10 years

Assuming a constant replacement rate until the units are retired, the number that will be replaced by electric equipment by 1985 are:

space heaters - 73%
water heaters - 92%
cook stoves - 65%
other - 100%

The amount of fossil fuel use in Chicago in 1974 in the residential and commercial sectors that is switchable is 786×10^{12} Btu. This number is calculated from data in Table 6-1 assuming that the Chicago commercial sector uses 29% of its oil demand for feedstock as is the case in the national demand pattern (see Table 3-5). The amount of existing fossil fuel use that is convertible by 1985 is then given by:

$$\begin{aligned}\text{Convertible energy} &= 786 \times 10^{12} \times \sum_{\text{end use}} (\%\ \text{equipment replaced}) \times \\ &\quad (\%\ \text{of switchable fossil fuel use}) \\ &= 786 \times 10^{12}\,[(.73)(.82) + (.92)(.13) + \\ &\quad (.65)(.04) + (1)(.01)] \\ &= 593 \times 10^{12}\ \text{Btu}\end{aligned}$$

In the industrial sector, the average life of existing equipment is assumed to be 20 years. Thus by 1985 the amount of existing fossil fuel usage that is converted is 24 x 10^{12} Btu. By the year 2000 all currently existing fossil fired equipment in the industrial sector that is convertible is assumed to be replaced (49 x 10^{12} Btu).

Step 3 - To determine the amount of electrical power required to meet the converted demand, it is necessary to consider the efficiencies of the electrical equipment and the replaced fossil fired equipment since the same amount of useful work is required in both cases. The following efficiencies of the equipment used in the residential and commercial sectors are taken from Appendix B.

hardware	fossil efficiency	electric efficiency
space heater	60%	150%*
water heater	60%	92%
cook stove	37%	78%**
other	assume same efficiency for both	

---

*average of resistence heating and heat pump

**combined conventional and microwave cooking

Thus the weighted average ratio of fossil fuel efficiency to electric efficiency is given by:

$$\text{efficiency ratio} = .82\,\frac{60}{150} + .13\,\frac{60}{92} + .04\,\frac{37}{78} + .01$$

$$= 0.44$$

The additonal electric energy required for the residential and commercial sectors is:

$$1985\text{: } (593 + 296) \times 10^{12} \times .44$$
$$= 391 \times 10^{12} \text{ Btu}$$

$$2000\text{: } (786 + 763) \times 10^{12} \times .44$$
$$= 682 \times 10^{12}$$

A similar weighted efficiency calculation for the industrial sector using data from Tables 7 and 8 in Appendix B yields:

$$\text{efficiency ratio} = 0.43$$

The additional electricity required in the industrial sector is:

$$1985\text{: } (24 + 21) \times 10^{12} \times 0.43$$
$$= 19 \times 10^{12}$$

$$2000\text{: } (49 + 66) \times 10^{12} \times 0.43$$
$$= 49 \times 10^{12}$$

Table 6-3 summarizes the projected energy demand for Chicago under Case II conditions.

TABLE 6-3

ESTIMATED FUTURE ENERGY DEMAND FOR CHICAGO AQCR, CASE II

	Annual Energy Usage (10^{12} Btu)	
Sector, fuel	1985	2000
Residential and commercial,		
fossil	193**	0**
electricity*	611	999
Industrial,		
fossil	749	1,199
electricity*	138	246

*electricity converted at 3,413 Btu/kwhr

**feedstocks not included

6.1.2 Additional Power Plant Requirements

The new power plants required are calculated from the information in Tables 6-1, 6-2, and 6-3. The amounts of additional electricity required are:

Case I - 1985: 105×10^{12} Btu = 3.08×10^{10} kwhr = 3,516 Mw
2000: 280×10^{12} Btu = 8.21×10^{10} kwhr = 9,327 Mw

Case II- 1985: 515×10^{12} Btu = 1.51×10^{11} kwhr = 17,237 Mw
2000: $1{,}011 \times 10^{12}$ Btu = 2.96×10^{11} kwhr = 33,790 Mw

To account for transmission and distribution losses, generation amounts are increased by 10%. Assuming that the plants will operate at 70% to 80% capacity factor, the amount of new capacity required is:

Case I - 1985: 5,000 Mw @ 77% capacity
2000: 14,000 Mw @ 73% capacity

Case II- 1985: 24,000 Mw @ 79% capacity
2000: 48,000 Mw @ 77% capapity

Assuming that the new capacity is installed in 1,000 Mw coal fired units, each with an SO_2 scrubber and electrostatic precipitator, yields the following plant parameters from Appendix C.

Stack height = 500 ft
Exit velocity = 60 ft/sec
Exit diameter = 34 ft
Exit temperature = 250°F
Exit flow rate = 3.28×10^6 ACFM
Heat input = 9.75×10^9 Btu/hr

Assuming a coal with 12,000 Btu/lb energy content yields a coal rate of 406 tons/hr. Assuming the Federal new source emission standards for SO_2, NO_x, and particulates are met yields the following emission rates at 100% load.

Particulates	975 lb/hr
SO_2	11,700 lb/hr
NO_x	6,225 lb/hr
CO	406 lb/hr
HC	122 lb/hr

The CO and HC emissions are computed from EPA emission factors for bituminous coal.

6.1.3 Emission Predictions

The emissions in the Chicago AQCR for the years 1974, 1985 and 2000 were projected for Cases I and II from the 1970 NEDS data. It was assumed that in the case of area sources the emissions growth rates were the same as the energy demand growth rates. The emissions from "open burning" were eliminated since this is no longer allowed in the Chicago area. The emissions from incineration were assumed to grow at the industrial sector energy growth rate. The controlled automotive emissions of NO_x, HC and CO were assumed to follow the EPA projected national trend. The uncontrolled auto emissions of SO_2 and particulates were assumed to grow at 3% per year.

The reduction in emissions in Case II for the residential and commercial sectors was assumed to be 100% when full conversion was attained. This implicitly assumes that the commercial feedstocks, which are not convertible, contribute negligable emissions.

The new point source emissions were assumed to be 50% less than that which they would be if they grew at the industrial sector energy use growth rate. This reduction in emissions is assumed to be provided by emission controls applied to new sources.

It should be noted that the emissions of existing electric utilities were removed from the point source total emissions before the latter were projected and then added back in afterwards. This was necessary since the new electrical generation requirements are met in all cases by the power plants discussed in the previous section.

The emissions of each power plant were reduced from the 100% levels given in the previous section by the capacity factor which is also given in the previous section.

Table 6-4 indicates the projected emissions for the Chicago AQCR.

6.1.4 Ambient Air Quality Predictions

The predictions of future ambient air quality were made using influence coefficient projections of the concentrations in the Chicago AQCR from concentrations predicted by dispersion modeling of the 1970 NEDS data for the AQCR. The dispersion model used is similar to the Climatological Dispersion Model (CDM) recently developed by EPA. This model, which is described more fully in Appendix D, was used to compute the annual average concentrations of the five pollutants at 100 receptors located in the AQCR (see Figure 6-1). Thirty-four of these receptors are located in the urban area and 66 are located in the rural area.

Prior to exercising the model the NEDS point source data were extensively edited to ensure a consistent input set. The sources with missing stack parameters were checked and where possible stack parameters were estimated using the guidelines derived by Engineering Sciences Inc. (EN-027). To reduce computer time, sources at the same location with the same stack parameters were combined into a single source with the same stack parameters but increased emission rates.

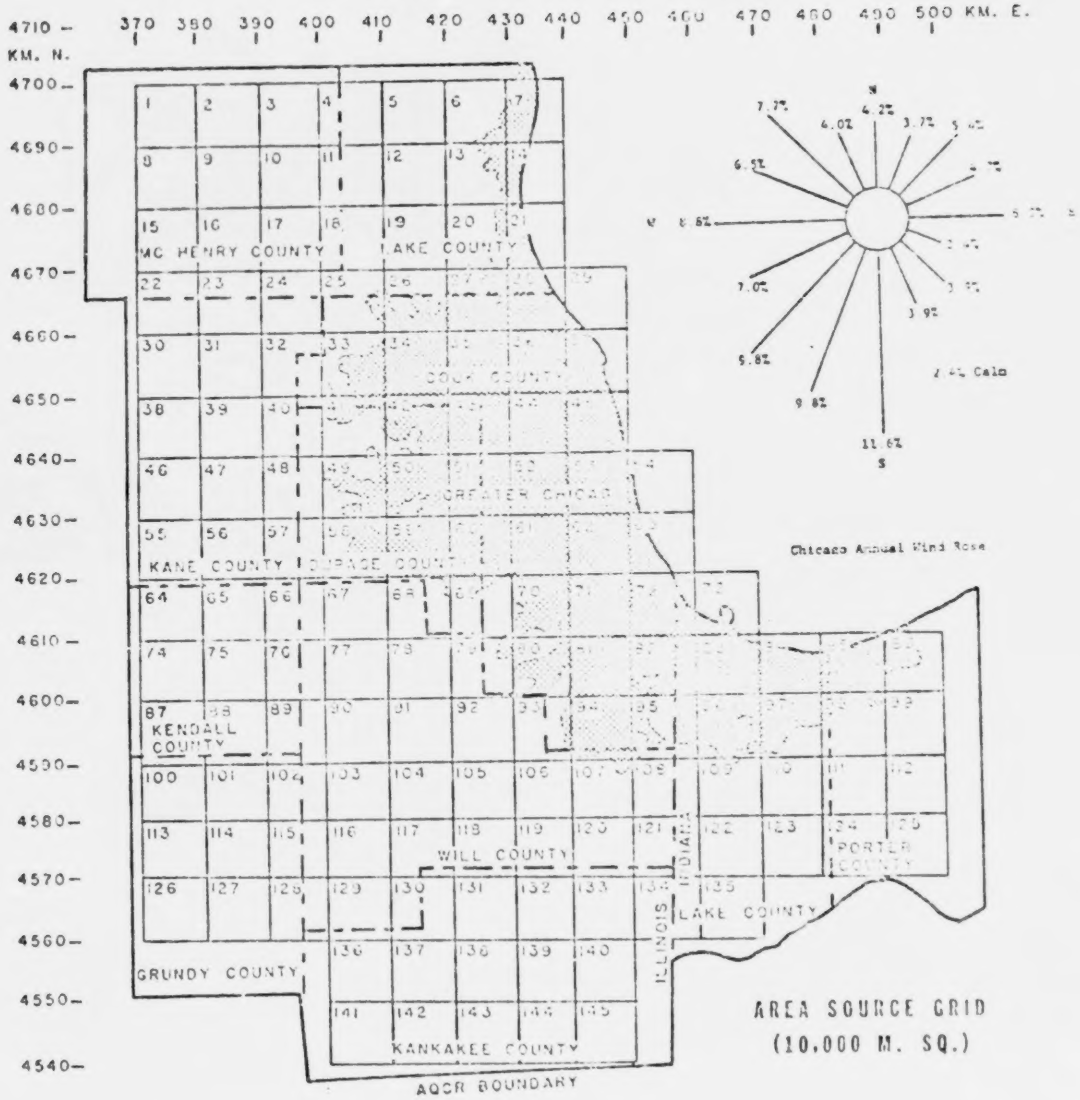
The area source data in the NEDS data base were used to define the emissions of the area source grid shown in Figure 6-2. The emissions of each area source are proportional to the population inside the area.

TABLE 6-4

PROJECTED EMISSIONS FOR THE CHICAGO AQCR

(tons/yr)

Case, Year, Source	Particulates	SO_2	NO_x	HC	CO
1974,					
Point Source	400,028	857,866	234,947	103,686	841,633
Area Source	206,579	302,842	314,451	442,204	1,668,609
Case I, 1985					
Point	486,895	943,294	258,217	126,597	1,029,106
Area	293,922	435,043	214,011	183,458	509,935
New Elec	18,187	197,297	181,974	6,845	2,056
Case I, 2000					
Point	678,878	1,132,952	309,876	177,461	1,445,311
Area	471,795	667,364	330,887	262,037	802,363
New Elec	48,249	523,734	483,059	18,171	5,457
Case II, 1985					
Point	462,489	919,484	251,732	120,205	976,863
Area	256,998	303,415	162,016	173,489	480,666
New Elec	89,510	971,624	896,163	33,711	10,125
Case II, 2000					
Point	621,028	1,075,882	294,331	162,156	1,320,072
Area	402,618	444,889	245,514	245,010	751,708
New Elec	174,488	1,894,052	1,746,951	65,715	19,737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GREATER CHICAGO
KANE COUNTY
DUPAGE COUNTY
KENDALL COUNTY
WILL COUNTY
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ILLINOIS
INDIANA
LAKE COUNTY
PORTER COUNTY
AQCR BOUNDARY
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9.8%
11.6%
Calm
Chicago Annual Wind Rose

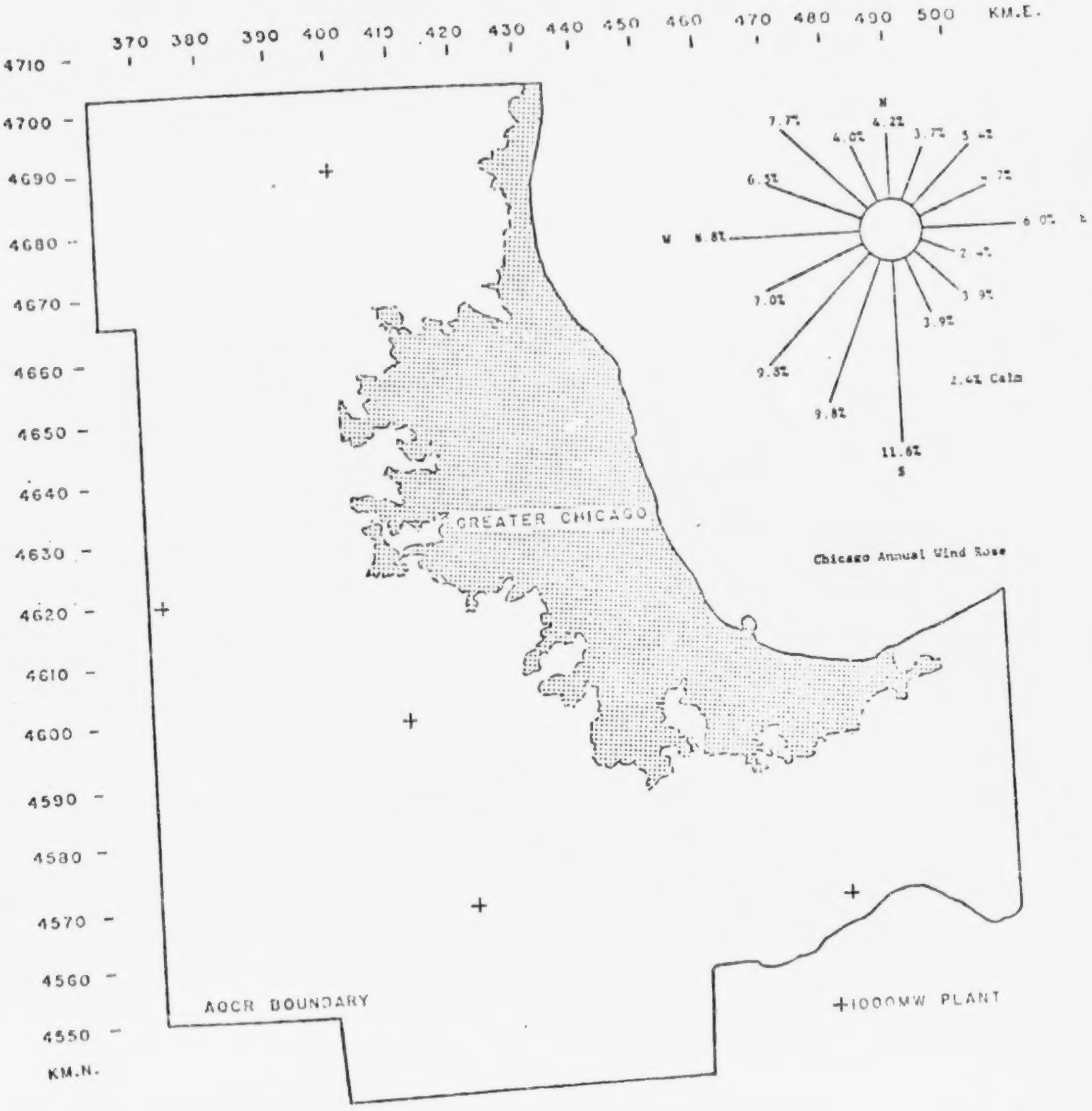
AREA SOURCE FOR CHICAGO

FIGURE 6-2

The dispersion modeling of the emissions was done in a piecemeal fashion to facilitate the calculation of the influence coefficient for the various source categories. The point sources were split into two groups – electrical generation and non-electrical generation, and the area sources were separated into urban area sources and rural area sources. Each of these four source types was modeled separately for the urban receptors and the rural receptors. The average concentrations for each of the two receptor types were then computed. When the average concentrations (urban or rural) of each of the four source types are added, the result is the total concentration due to all sources.

Also computed using the dispersion model were the concentrations produced by the additional power plants required in 1985 and 2000 for Case I and Case II. To perform this modeling it was necessary to site the power plants. This was done using the guideline that "increased electrical usage in future years will be provided by new or expanded central power stations at projected sites within the AQCR, but remote from population centers". Except for this constraint, the power plants were arbitrarily located. The locations and sizes are shown in Figure 6-3 through 6-6. The large number of relatively small (1,000 Mw) power stations used for Case I was chosen in deference to concern over significant deterioration while in Case II it was assumed that for practical reasons larger installations would be used.

Influence coefficients for point sources were calculated by dividing each point source produced average pollutant concentration (both rural and urban) by the respective point source emissions. A similar procedure was used for area sources that affected receptors not directly under them (e.g., urban area sources affecting rural receptors). In the case of area sources overlying the receptors (e.g., urban area sources affecting urban receptors) the pollutant concentration was divided by the average strength (emissions per unit area) of the overlying area sources.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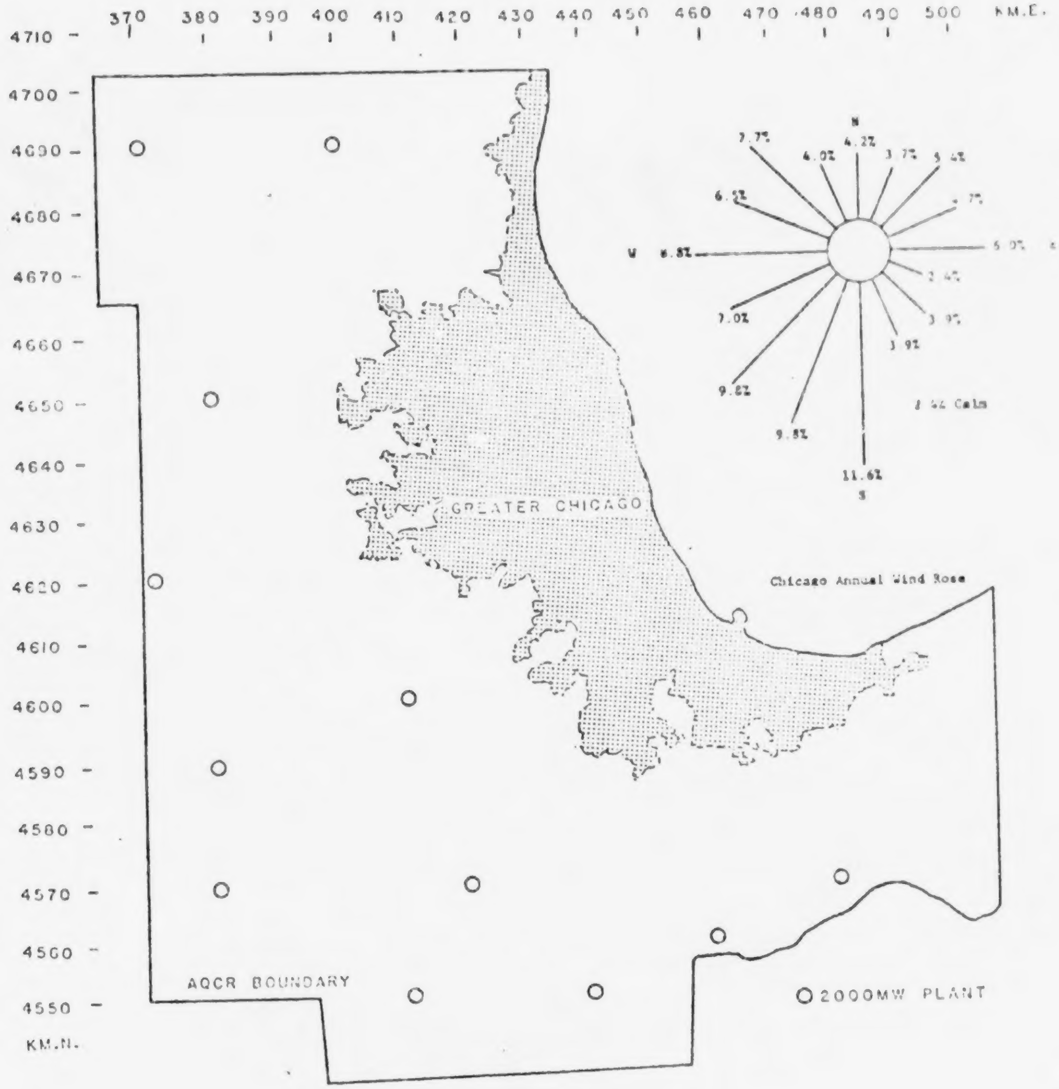
Chicago Annual Wind Rose

POWER PLANT LOCATIONS - 1985 CASE I

FIGURE 6-3



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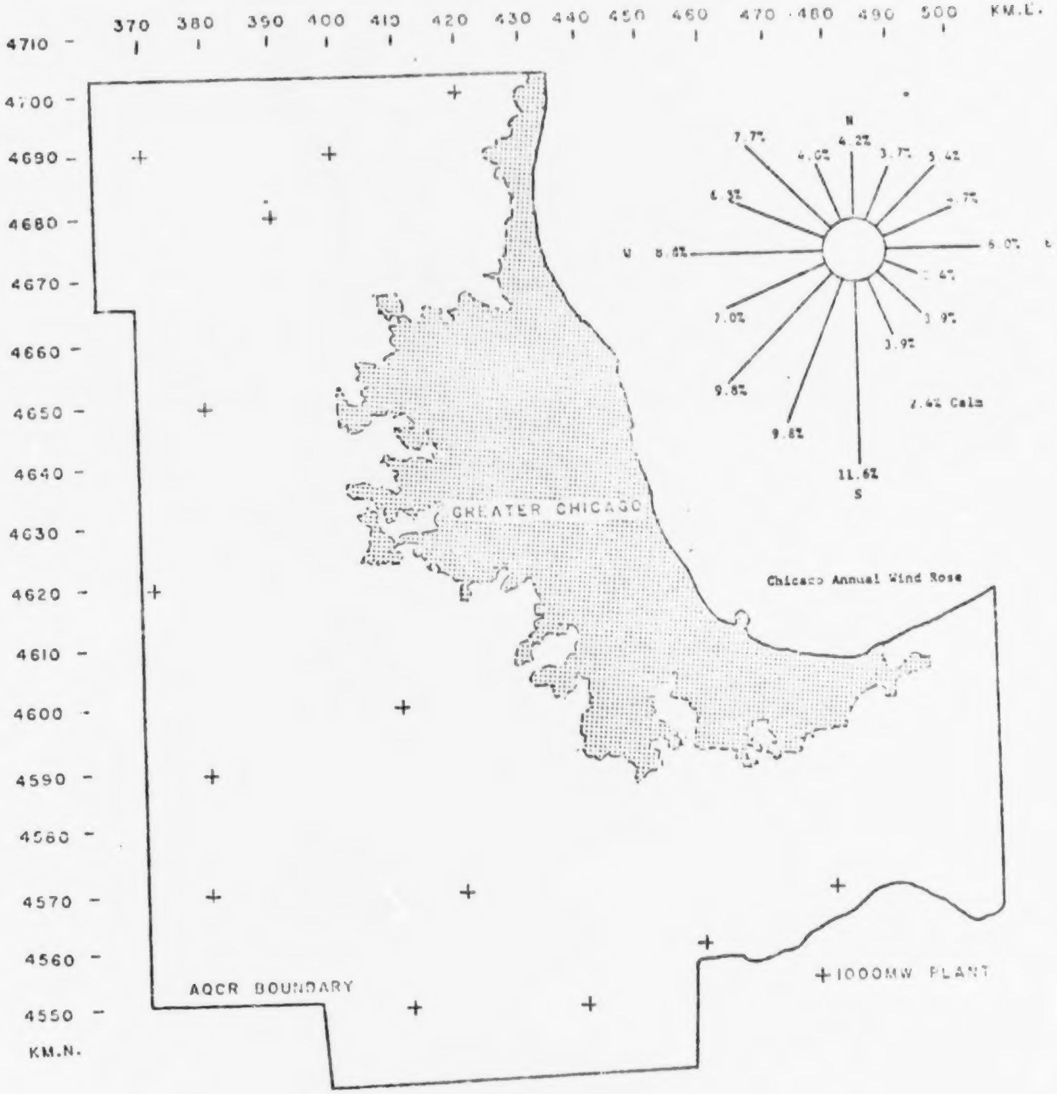
○ 2000MW PLANT

POWER PLANT LOCATIONS - 1985 CASE II

FIGURE 6-4



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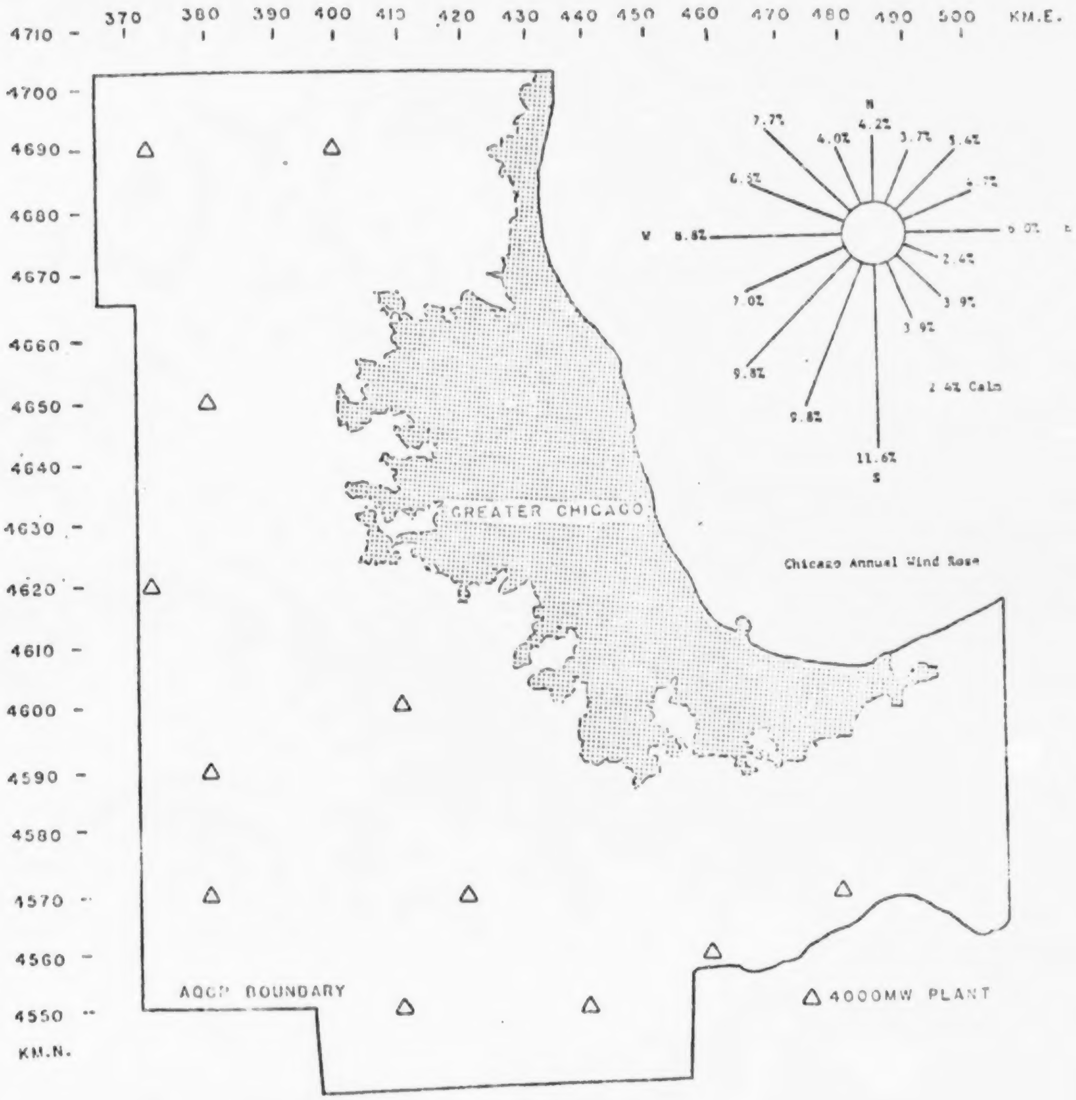
+ 1000MW PLANT

POWER PLANT LOCATIONS - 2000 CASE I

FIGURE 6-5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2.4% Calm
Chicago Annual Wind Rose

POWER PLANT LOCATIONS - 2000 CASE II

FIGURE 6-6

These influence coefficients were used in conjunction with the projected emissions for Cases I and II in the years 1985 and 2000 to predict the ambient concentrations produced by all area sources and point sources except for the electrical generation sources. The concentrations due to electric generation (both existing and projected) were added in after having been determined by dispersion modeling.

The concentrations for the above noted cases and years were computed for two types of geographic distributions of emissions. The first type, which results from essentially no geographic growth (Type 1 growth), has all point and area source emissions emanating from the same relative locations as at present. The second type, which results from extensive geographic growth (Type 2 growth), has all new point source emissions emanating from rural areas and new area source emissions emanating from the outskirts of the present urban area.

The air quality projections for Type 1 growth were made using the point and area source influence coefficients discussed above. The air quality projections for Type 2 growth were made using point source influence coefficients computed from the twelve 4,000 Mw power plants and area source influence coefficients as before. The power plant influence coefficients were used for the new point sources because they are more representative of large point sources located in rural areas.

In the Type 1 growth projections the urban area remained constant at 3,326 km^2 through the year 2000 while for Type 2 growth the urban area was 4,604 km^2 in 1985 and 8,801 km^2 in 2000.

6.2 Results

The ambient air pollutant concentrations derived using the previously discussed methodology are shown in Table 6-5, and the concentration reductions (from corresponding Case I levels) due to increased electrical use are shown in Table 6-6. The negative entries in Table 6-6 indicate that the concentrations of those pollutants increased rather than decreased.

In Table 6-6 it can be seen that intensive electricity usage improves the rural air quality as far as particulates, hydrocarbons, and CO are concerned, does not change SO_2 levels, and increases NO_x levels. The urban air quality is improved for all pollutants up to as much as 17% for SO_2. This SO_2 concentration reduction is due primarily to the conversion of coal usage in the residential and commercial sectors. If this coal usage were not converted, then the SO_2 levels (both urban and rural) probably would increase with increased electrical usage.

The beneficial effects of increased electrical usage tend to be greater in the Type 1 growth cases than in the Type 2 growth cases. However, it is interesting to note that the growth patterns have a larger effect on ambient air quality than intensive electrical substitution.

TABLE 6-5

COMPUTED AMBIENT AIR QUALITY

($\mu g/m^3$)

	Urban Receptors					Rural Receptors				
	Particulates	SO_2	NO_x	HC	CO	Particulates	SO_2	NO_x	HC	CO
1974 (Baseline)	131	128	96	128	529	34	42	28	34	134
Type 1 Growth*										
1985 Case I	170	172	74	65	254	45	56	23	18	65
1985 Case II	157	146	66	60	242	42	56	25	17	62
2000 Case I	255	252	111	90	379	67	82	35	26	96
2000 Case II	227	208	98	84	352	61	82	39	24	90
Type 2 Growth**										
1985 Case I	135	137	58	49	199	42	54	23	17	61
1985 Case II	128	122	54	47	193	40	54	25	17	59
2000 Case I	143	147	63	49	212	56	76	33	24	87
2000 Case II	135	136	63	47	204	53	77	38	22	82

* No geographic growth in emission sources

** Extensive geographic growth in emission sources

TABLE 6-6

POLLUTANT CONCENTRATION DECREASE DUE TO INTENSIVE ELECTRICAL USE

$\mu g/m^3$ (% reduction)

	Urban Receptors					Rural Receptors				
	Particulate	SO_2	NO_x	HC	CO	Particulates	SO_2	NO_x	HC	CO
1985 Type 1 Growth	13 (8%)	26 (15%)	8 (11%)	5 (8%)	12 (5%)	3 (7%)	0 (0%)	-2 (-9%)	1 (6%)	3 (5%)
2000 Type 1 Growth	28 (11%)	44 (17%)	13 (12%)	6 (7%)	27 (7%)	6 (9%)	0 (0%)	-4 (-11%)	2 (8%)	6 (6%)
1985 Type 2 Growth	7 (5%)	15 (11%)	4 (7%)	2 (4%)	6 (3%)	2 (5%)	0 (0%)	-2 (-9%)	0 (0%)	2 (3%)
2000 Type 2 Growth	8 (6%)	11 (7%)	0 (0%)	2 (4%)	8 (4%)	3 (5%)	-1 (-1%)	-5 (-15%)	2 (8%)	5 (6%)

7.0 PROJECTION OF THE MAXIMUM RATE OF ELECTRICAL SUBSTITUTION

This section presents an estimate of the rate at which electrical equipment would have to be manufactured and installed in order to provide for replacement of direct-fired fossil fuel equipment between the present and the years 1985 and 2000. The rate at which new power plants would have to be constructed in order to meet the increased demand for electrical energy which would result from this substitution is also considered. These requirements were evaluated based on historical and projected activity in equipment manufacture and power plant construction including an assessment of the impact on these two industries of attaining various levels of fossil fuel equipment replacement. Primary consideration was given to end use applications in the residential and commercial sectors as more than 90% of the convertible fossil fuel is consumed in these sectors.

7.1 Equipment Manufacture

Three different cases were utilized to assess the impact of the rate of electrical equipment manufacture on replacement of direct-fired fossil fuel equipment with electrical equipment. The basis for these three cases are described below:

Case I: Historical trends in the manufacture of electrical equipment will continue in the future. When existing equipment is retired it will be replaced by similar equipment (fossil fuel by fossil fuel, electrical by electrical). There are no artifically imposed incentives for conversion to or installation of electrical equipment. In other words, the status quo will be maintained through the year 2000.

Case II: All new installations will be electrical equipment. When existing equipment is replaced, similar replacement equipment will be used (fossil fuel will be replaced by fossil fuel, electrical will be replaced by electrical).

Case III: All new installations will utilize electrical equipment. Existing fossil fuel equipment will be replaced by electrical equipment as the existing fossil fuel units are retired, and electrical equipment will be replaced by electrical equipment.

For each case, the total number of required units (fossil fuel and electric) required for new installations are assumed to be 1.5 million per year based on historical data and projections of new housing construction by the Department of Commerce (HO-188). The Department of Commerce's statistics (Figure 7-1) cover only new housing neglecting some of the equipment demands in the commercial sector (office buildings, etc.). As a result, 1.5 million new installations per year is probably a somewhat conservative figure; nevertheless, the conclusions of this section should not be altered as the relative rates of production for each case study would remain about the same.

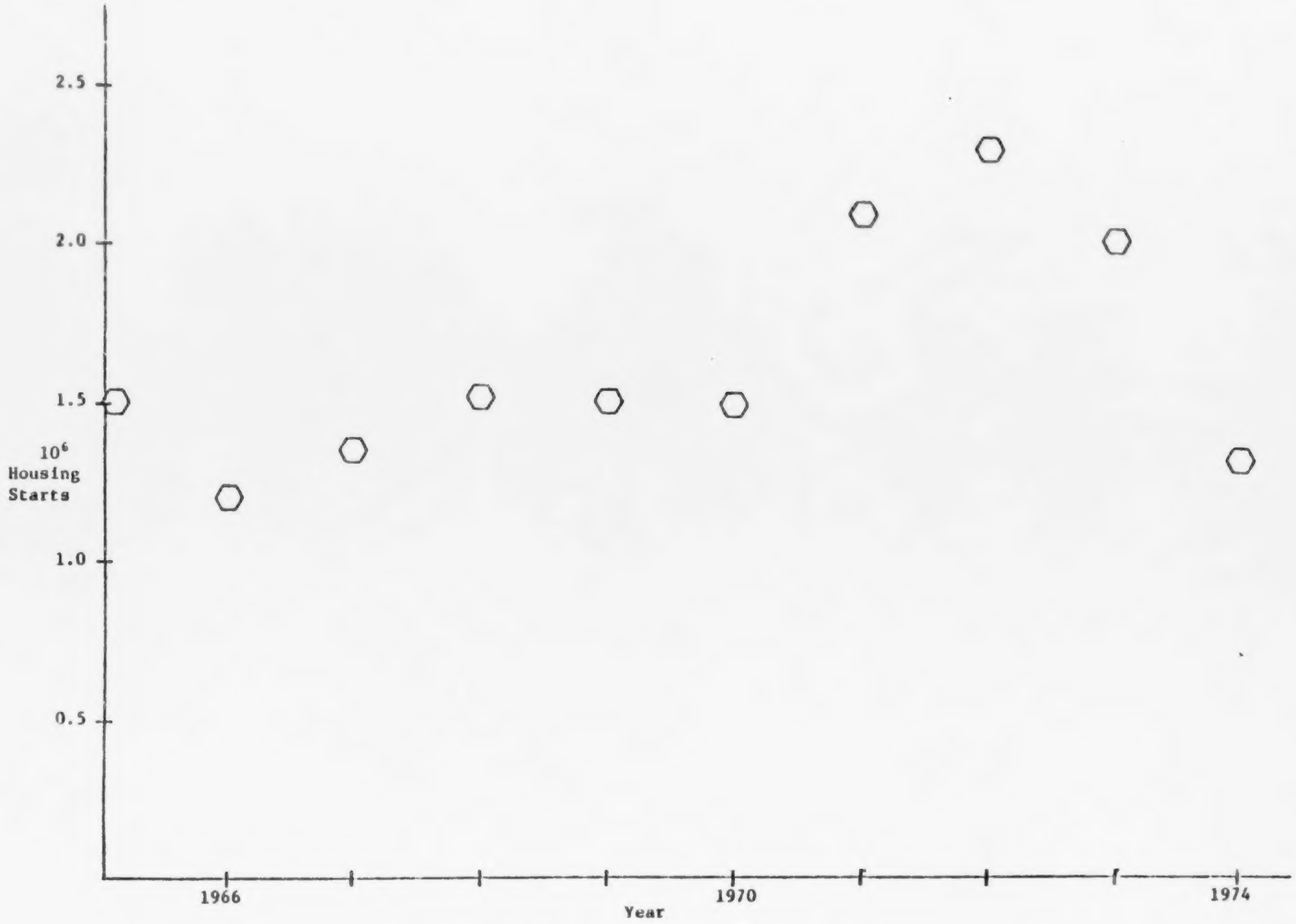

FIGURE 7-1 NEW HOUSING STARTS

7.1.1 Residential and Commercial Space Heat Equipment

Space heat accounted for 74% of the total convertible fossil fuel consumed in 1968, and since more than 98% of the space heating in the residential and commercial sectors was accomplished by fossil fuels, conversion of this end use to electrical equipment would have by far the greatest impact on the electrical equipment manufacturers.

Figure 7-2 presents the rates at which electrical, natural gas, and oil space heating equipment have been manufactured between 1960 and the present. This plot indicates the relative trends of equipment manufacture for the three types of space heat equipment included in this study (electrical, natural gas-fired, and fuel oil-fired). By assigning a finite lifetime to each type of equipment, manufacturing requirements to meet replacement demands due to retired units can be projected. For example, in 1985 it was assumed that electrical replacement units would have to be produced for each electrical unit manufactured and installed in 1965 (see Figure 7-2). The lifetimes used for the various equipment types are electrical – 20 years, natural gas – 15 years, and fuel oil – 15 years (DA-122, GR-139, EQ-002). Obviously, not every electrical space heating unit produced in 1965 will be replaced in 1985; some will be replaced sooner, others later. Nevertheless, assigning finite lifetimes to each type of space heating equipment should not affect the relative rate of production required for the three cases examined.

Figure 7-3 presents a projection of the required rate of manufacture of electrical equipment between the present and the year 2000 for each of the three cases being considered. For Case I it was assumed that one-half of all new installations will be electrical space heating equipment (KI-093). Therefore,

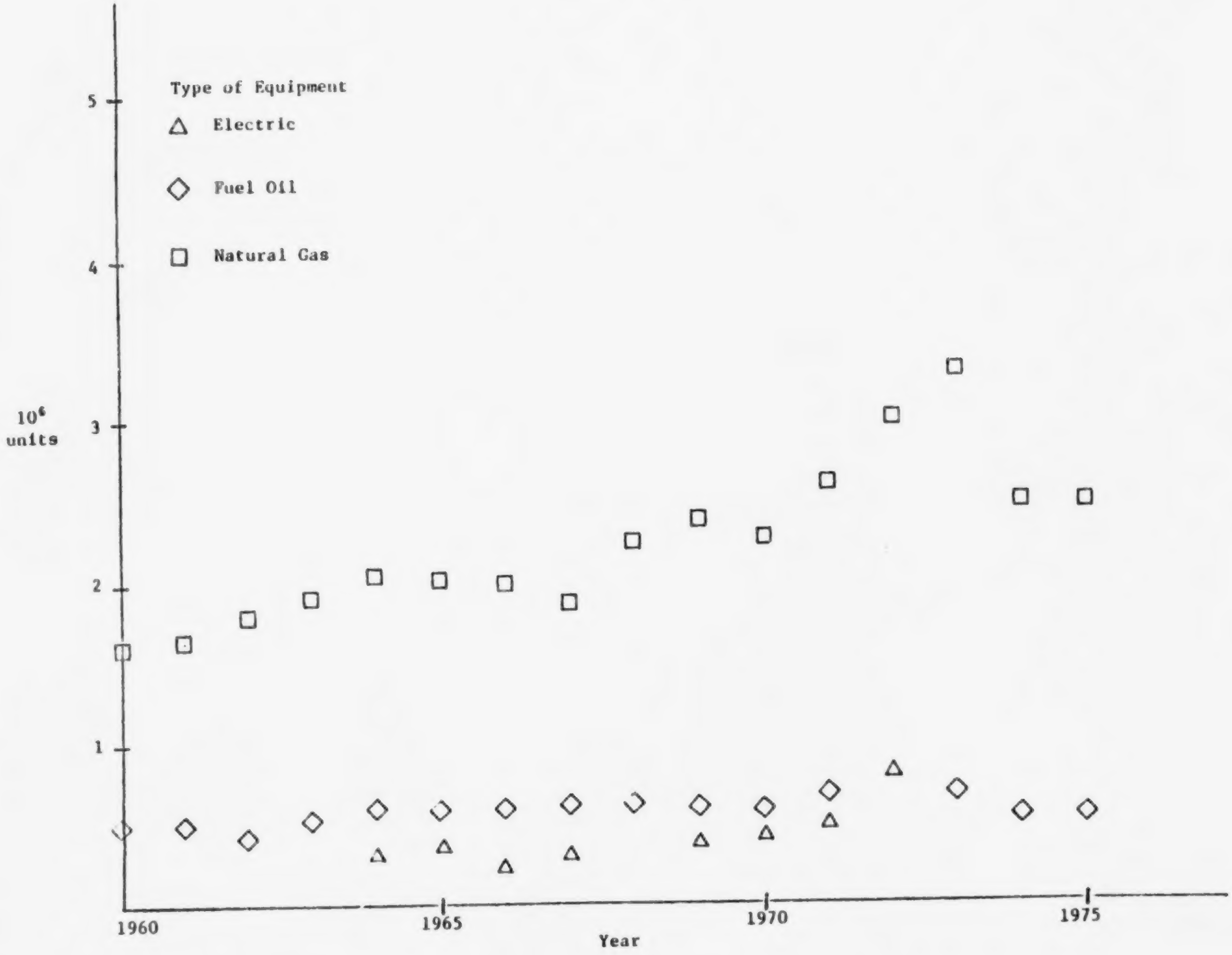

FIGURE 7-2 HISTORICAL PRODUCTION OF SPACE HEATING EQUIPMENT

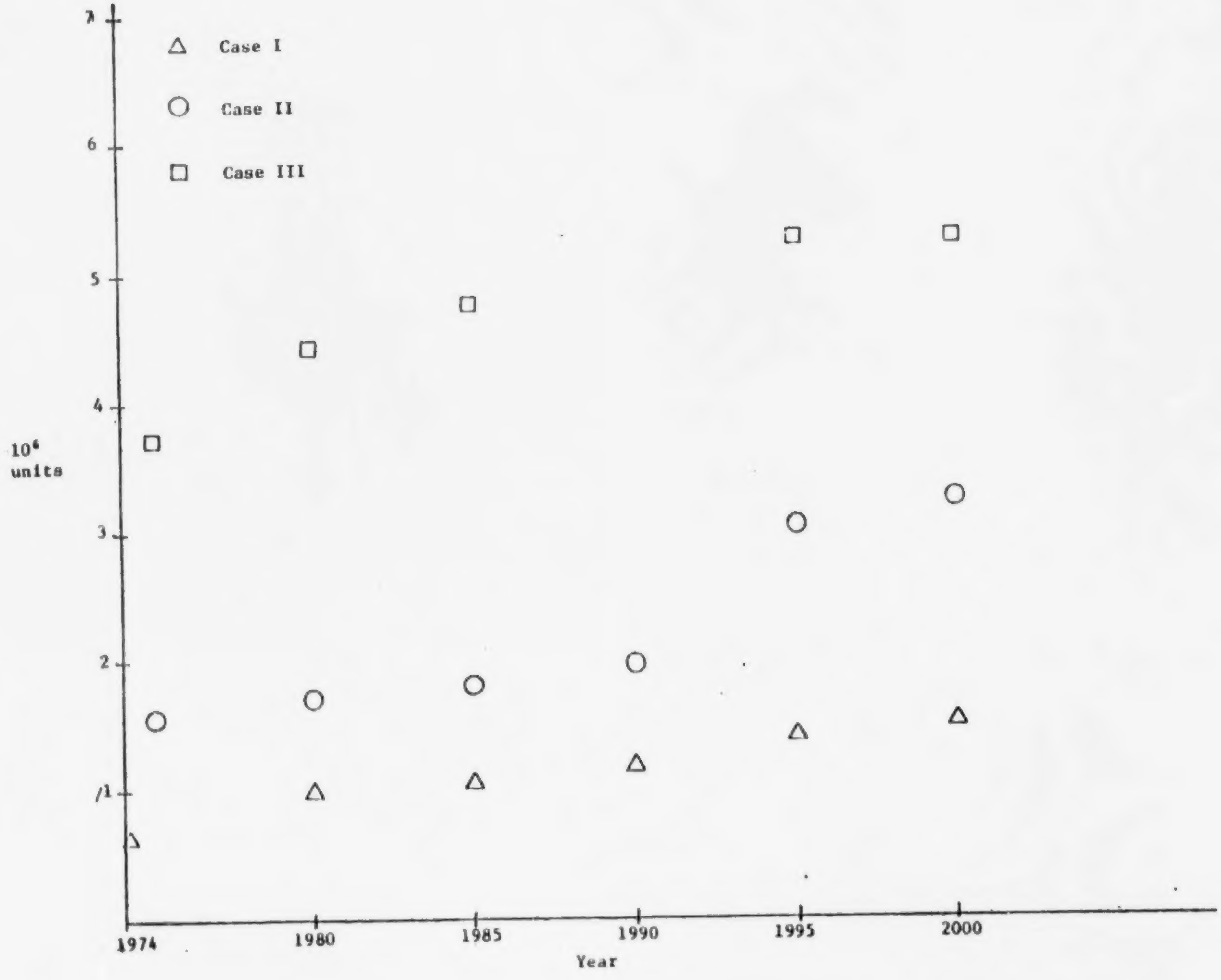

FIGURE 7-3 PROJECTION OF REQUIRED PRODUCTION OF SPACE HEATING EQUIPMENT

the required rate of production in year X between 1975 and 2000 is projected to be .75 million (one-half of the 1.5 million new installations each year) plus replacement units for electrical equipment installed in year X-20 (see Figure 7-2). In 1985, this would result in a projected required production rate of .75 million new installations plus .4 million replacement units (electrical equipment installed in 1965, see Figure 7-2) for a total of 1.15 million units. For the year 2000, the projected required rate would be .75 million new installations plus .8 million replacements (projected installations in 1980, see Figure 7-3) for a total of 1.55 million units.

For Case II, all new installations would be electric (1.5 million units per year) with replacements being the same type of space heater as the retired equipment. Therefore, the projected required rate of production for electrical units in any given year between 1975 and 2000 is 1.5 million new installations plus the number of electrical space heaters installed in the year X-20. In 1985 the projected required rate of manufacture is 1.5 million plus .4 million (installations in 1965, see Figure 7-2) for a total of about 1.9 million. The projected required rate of production for 2000 is about 3.4 million units (Figure 7-3).

Case III assumes that all new installations will be electrical equipment and that existing fossil fuel equipment will be replaced by electrical equipment as the fossil fuel units are retired. Electrical space heaters will have electrical replacements as in Case I and II. Therefore, for any given year X between 1975 and 2000, the projected required rate of production of electrical space heat equipment is 1.5 million new installations plus the electrical units installed in the year X-20 plus the fossil fuel units (natural gas and fuel oil-fired) installed in the year X-15. Case III results in a projected required rate of manufacture in 1985 of 1.5 million new installations plus .4 million electric replacements plus 2.9 million fossil fuel replacements for a total of about 4.8 million electric space heaters. By 2000 the projected required rate of production would be about 5.25 million units.

7.1.2 Residential and Commercial Water Heating Equipment

Water heating accounted for about 11% of the total convertible fossil fuel consumed in all three sectors in 1968 with over 83% of the water heating in the residential and commercial sectors accomplished using direct-fired fossil fuel equipment. Conversion of this end use to electrical equivalents would have the second greatest impact on the electrical equipment manufactures.

Figure 7-4 presents the rates at which electrical and natural gas water heating equipment have been manufactured between 1960 and the present. Fuel oil equipment was not included as less than 10% of the total fossil fuel consumed for this use in the residential and commercial sectors in 1968 was fuel oil (see Table 3-1). This plot indicates the historical trends of equipment manufacture for the two types of water heating equipment considered, and with assignment of a finite lifetime to each type of equipment, allows projection of manufacturing requirements to meet replacement demands due to retired units. The lifetimes used are the same for electric and natural gas water heaters - 12 years (GR-139).

Projections of the required rate of production of electrical water heating equipment between the present and the year 2000 for each of the three cases discussed previously is presented in Figure 7-5. For Case I it was assumed that

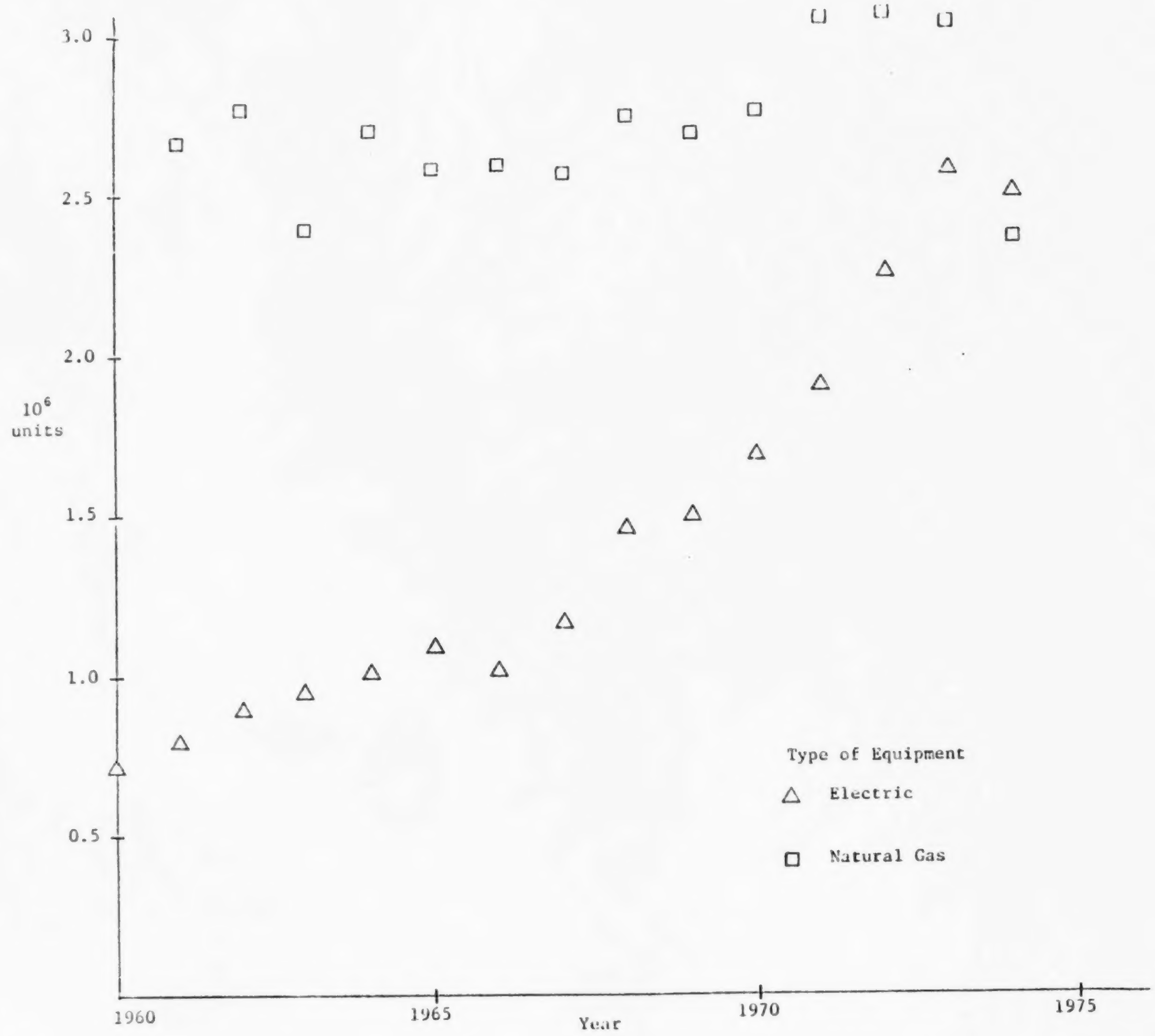

FIGURE 7-4 HISTORICAL PRODUCTION OF WATER HEATING EQUIPMENT

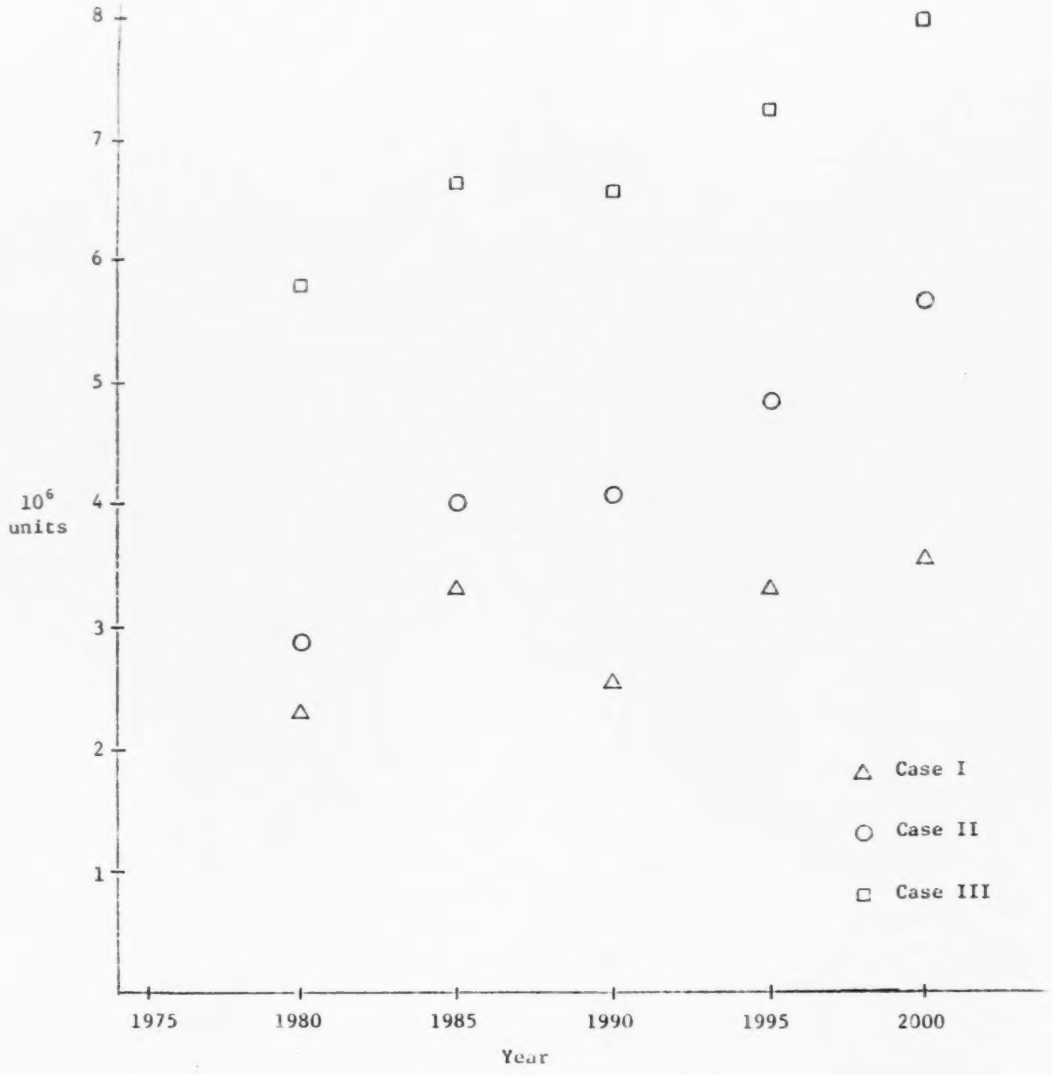

FIGURE 7-5 PROJECTION OF REQUIRED PRODUCTION OF WATER HEATING EQUIPMENT

one-half of all new installations will be electric units (TE-177). These projections were determined for each case in a manner analogous to that for space heating. Case I projections of required manufacturing rates for any year X between 1975 and 2000 are .75 million new installations (one-half the 1.5 million new installations per year) plus replacements for electrical equipment installed in the year X-12 (see Figure 7-4). Therefore, the projected required rate of production of electric water heaters is about 3.2 million units in 1985 and about 3.6 million units in 2000.

For Case II the projected rate for any year X between 1975 and 2000 would be 1.5 million new installations plus replacements for electrical units installed in the year X-12. In 1985 the projected required rate of manufacture is about 4 million units and in 2000 about 5.4 million units.

For Case III, the projected rate for any year X between 1975 and 2000 would be 1.5 million new installations plus replacements for electrical units installed in X-12 plus replacements for natural gas units installed in X-12. This would result in a projected required rate of production of about 6.6 million electric water heaters in 1985 and about 8 million in 2000.

7.1.3 Residential and Commercial Cooking Equipment

Cooking accounted for about 3.8% of the total convertible fossil fuel consumed in all three sectors in 1968 with over 86% of the cooking in the residential and commercial sectors accomplished using direct-fired fossil fuel equipment. The impact of conversion of this end use to electrical equipment would be the third largest for the manufacturers in relation to other end use conversions examined.

The historical rates at which electric and natural gas cooking equipment have been produced from 1960 to 1974 are presented in Figure 7-6. Since less than 10% of the total fossil fuel consumed for this end use in the residential and commercial sectors in 1968 was fuel oil, cooking accomplished with fuel oil was not included (see Table 3-1). Relative trends of equipment manufacture for the two types of cooking equipment included are indicated by these plots, and with assignment of a finite lifetime to each type of equipment, a projection of production requirements to meet replacement demands as units are retired is possible. For electrical cooking units the lifetime is 20 years and for natural gas units the lifetime is 17 years (GR-139).

Figure 7-7 presents projections of the required rate of manufacture of electrical cooking equipment between the present and the year 2000 for each of the three cases. One-half of all new installations are assumed to be electrical units in Case I (TE-177). As for end uses previously discussed, projected required production for any year X between 1975 and 2000 is the sum of new installations (.75 million per year and replacements (electrical units installed in the year X-20). Therefore, the Case I projected required rate of manufacture of electric cooking equipment for 1985 is about 2.8 million units and for 2000 about 3.5 million units.

The sum of 1.5 million new installations and replacements for electrical equipment installed in the year X-20 gives the projected required rate of production based on Case II assumptions for any year X between 1975 and 2000. As can be seen from Figure 7-7 the projected rate is approximately 3.5 million units in 1985 and approximately 4.5 million units in 2000.

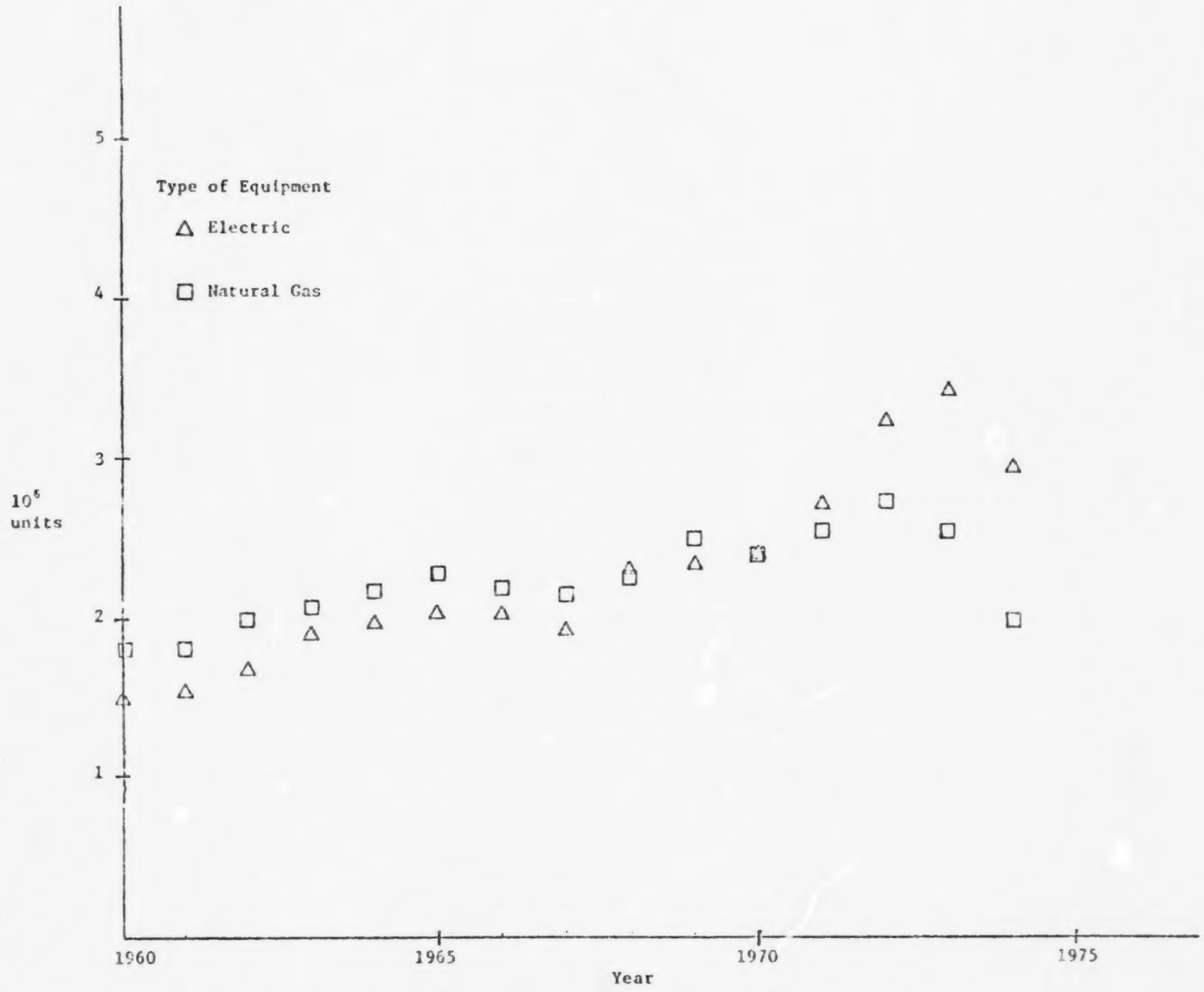

FIGURE 7-6 HISTORICAL PRODUCTION OF COOKING EQUIPMENT

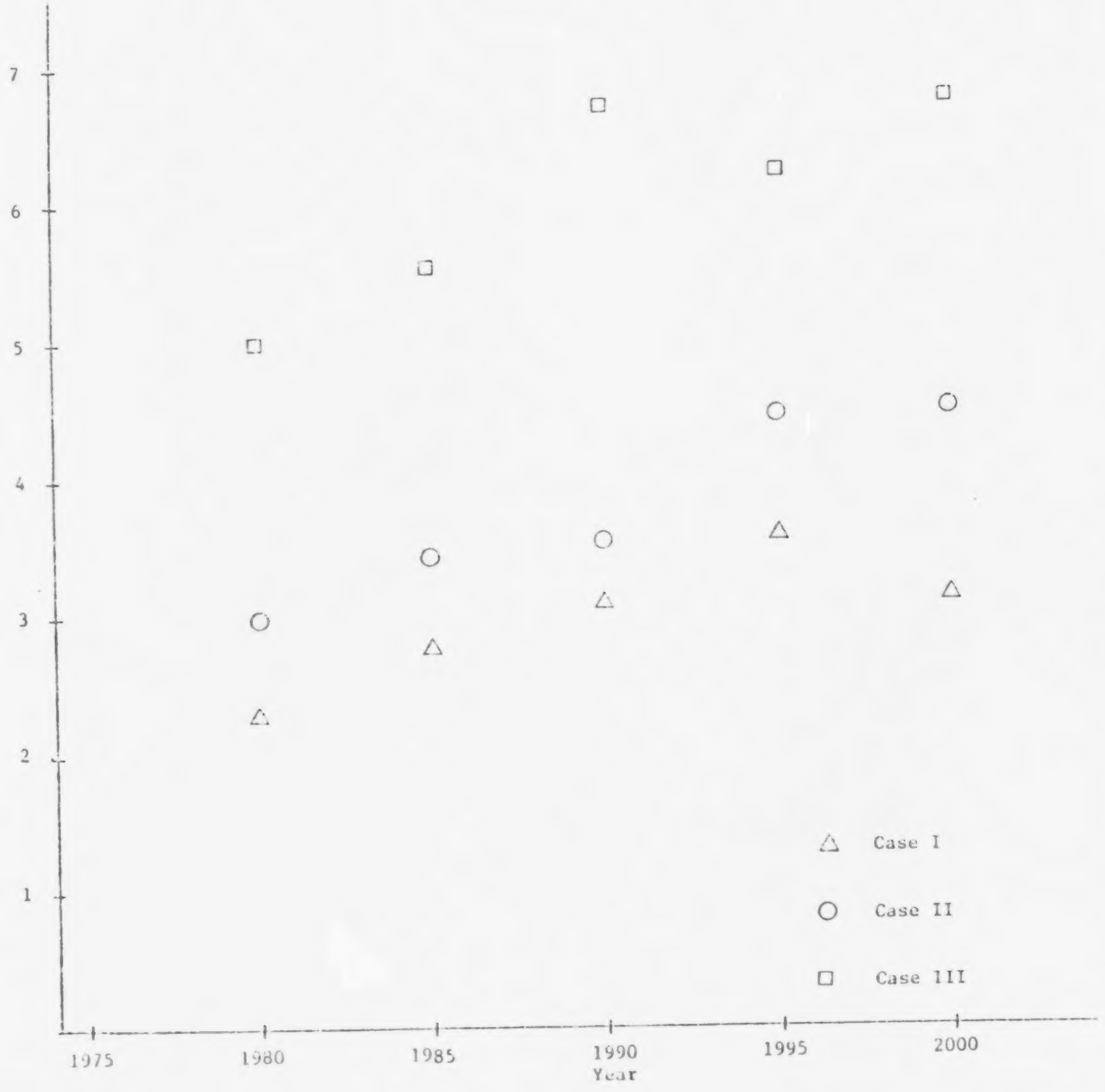

FIGURE 7-7 PROJECTION OF REQUIRED PRODUCTION OF COOKING EQUIPMENT

For Case III, the projected required rate in any year X is the sum of 1.5 million new installations, and electrical replacements for electrical equipment installed in the year X-20 and fossil fuel equipment installed in X-17. By 1985 the projected required annual production rate would be about 5.6 million units and about 6.8 million units by 2000.

7.2 Electrical Generation Capacity Expansion

Any conversion of direct-fired fossil fuel equipment to electrical equipment will result in an increased demand for electricity and, therefore, will require new construction of electric generating facilities. The ability of the power industry to meet these increased demands must be considered in projection of a maximum practicable rate at which electrical equipment can be applied in the residential, commercial, and industrial sector. Sufficient electrical energy must be available if an efficient conversion to electrical equipment is to be accomplished.

Electric generating capacity requirements were evaluated based on projected activity in power plant construction including an assessment of the impact on this industry of attaining various levels of fossil fuel equipment replacement.

7.2.1 Methodology Used to Project Generating Capacity Expansion Rates

As in Section 7.1 three separate cases were utilized to assess the impact of the rate of central power plant construction and expansion on the rate of conversion to electrical equipment . These three cases are described below:

Case I: Literature projections of electric generating capacity were assumed to represent the capacity required to satisfy the assumptions described for Case I in Section 7.1. No artificially imposed incentives for expansion of construction were assumed to exist.

Case II: Electricity demand was determined by assuming that the increased fossil fuel usage as projected for 1985 and 2000 was due to new installations that would be converted to electrical equipment. This calculated additional demand represents the effect of the assumptions described for Case II in Section 7.1. Conversion of this fossil fuel consumption to electric generating capacity is described in a later section.

Case III: For the year 1985, generating capacity required to meet the additional demand resulting from the Case III assumptions previously discussed in Section 7.1 were determined by summing the fossil fuel usage for each pertinent end use in the year (1985 - end use equipment lifetime) and conversion to equivalent generating capacity. This additional increment of capacity was then added to the Case II projection. For the year 2000, it was assumed that all fossil fuel equipment in the residential and commercial sectors had been replaced by electrical equipment. Therefore, the required additional generating capacity was determined by conversion of this fossil fuel energy requirement to equivalent generating capacity. This additional capacity was added to the Case I projection rather than the Case II projection, as the Case II additional increment is included in the total fossil fuel usage in the year 2000.

These projections include a load factor of 64% for 1985 and 66% for 2000 in calculation of installed generating capacity (HI-048). The relative efficiencies of the electrical and fossil fuel equipment were considered in the conversion of fossil fuel usage to equivalent electric generating capacity. Transmission losses were felt to be negligible since the average transmission distance was assumed to be 30 miles.

7.2.1.1 Case I Requirements

Projections of generating capacity vary with the source depending on several factors such as the date of the study and the basis for the projection. Figure 7-8 presents the projections of Radian, Electrical World, Hittman, and the Federal Power Commission. Radian's Case I projection is assumed to represent the required generating capacity necessary to satisfy the demand resulting from Case I criteria since Radian's study (see Section 3) is the most recent and is in good agreement with the other projections. The required generating capacity for 1985 is about 750 x 10^3 megawatts (Mw) and for 2000 about 1500 x 10^3 Mw.

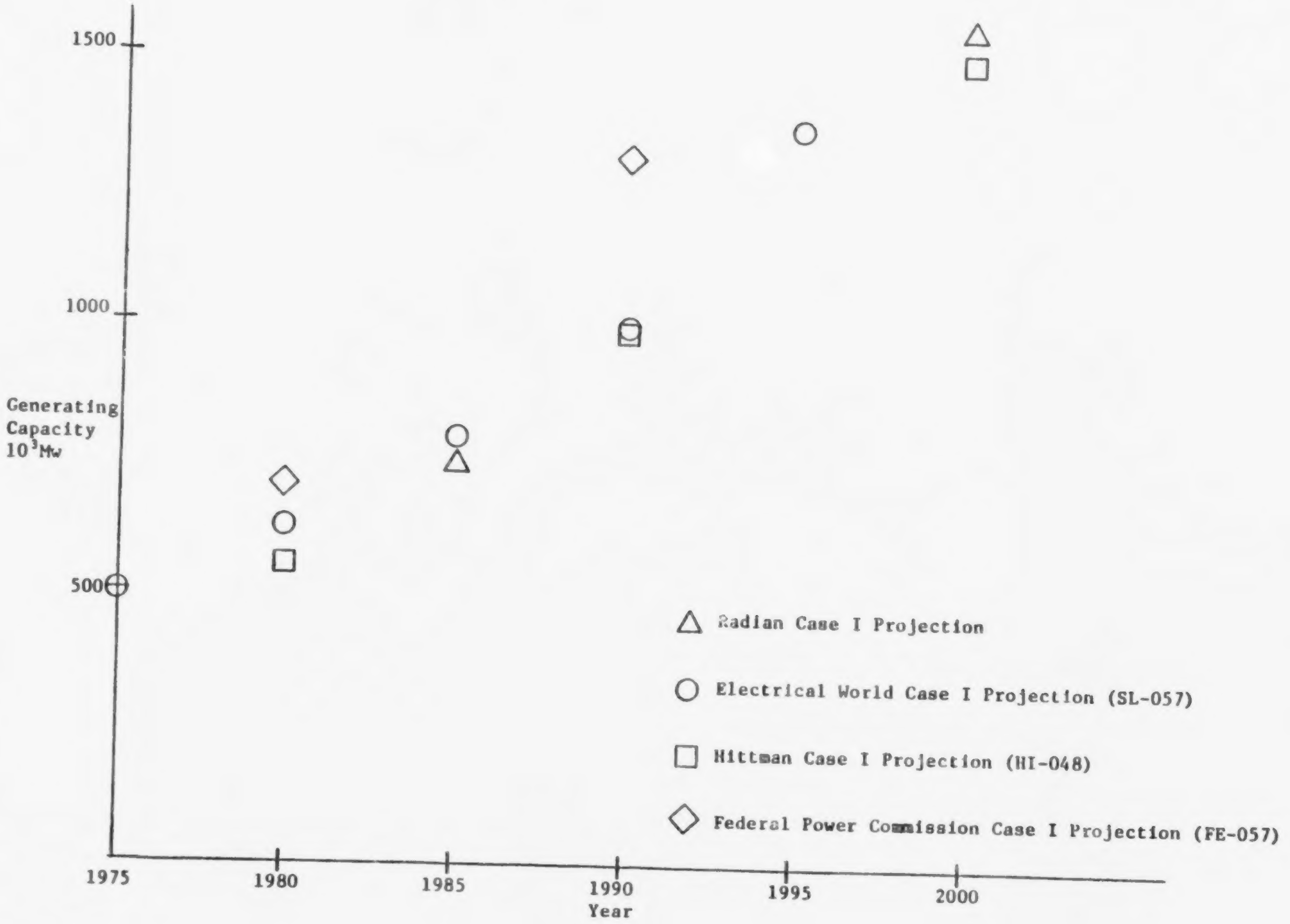

FIGURE 7-8 PROJECTION OF REQUIRED GENERATING CAPACITY

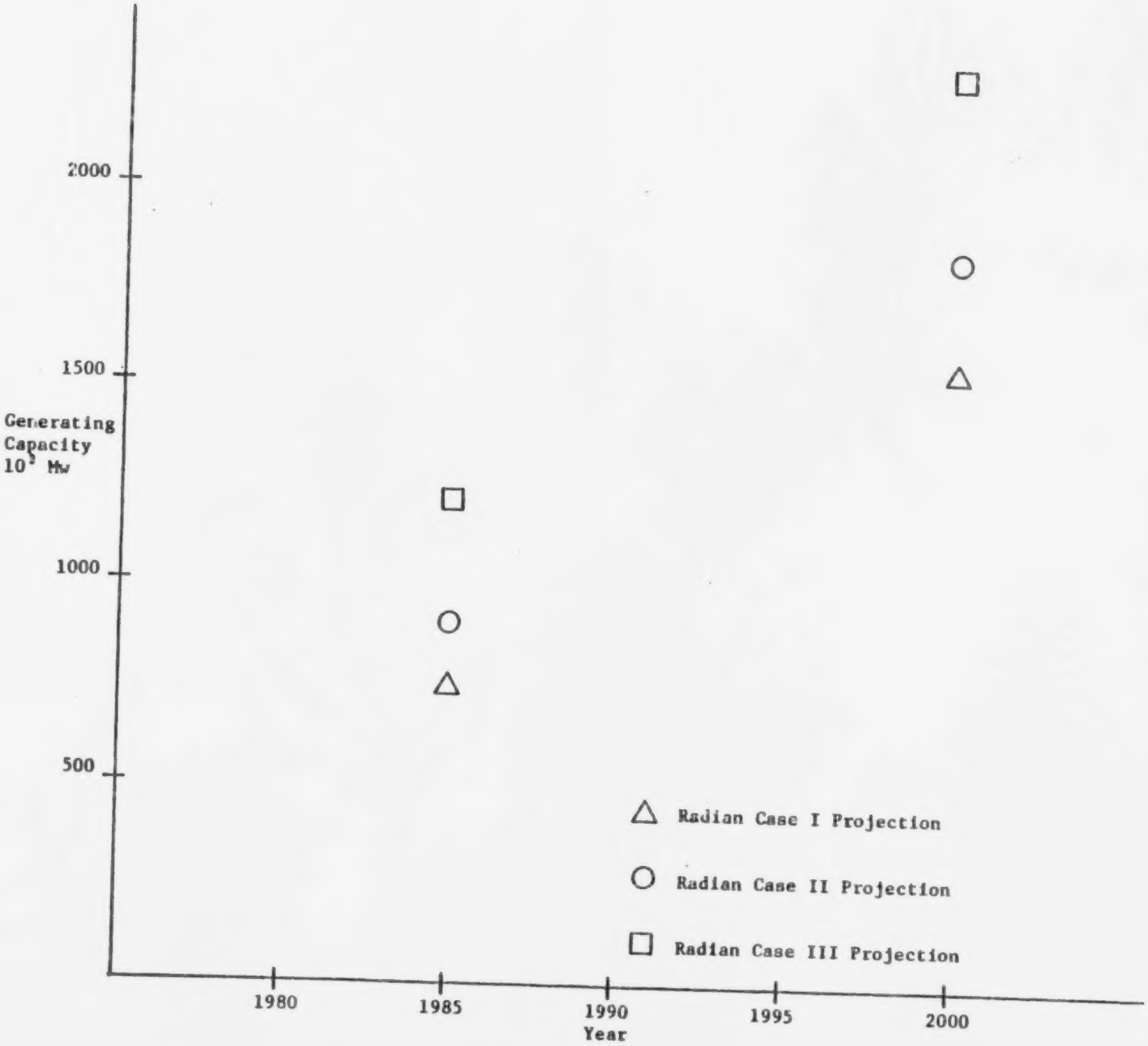

FIGURE 7-9 PROJECTION OF REQUIRED GENERATING CAPACITY

7.2.1.2 Case II Requirements

Case II requires that increased consumption of fossil fuels in the residential and commercial sectors (which would primarily result from new installations) be converted to electrical energy. If the increased fossil fuel consumption in the residential and commercial sectors between 1972 and 1985 and 1972 and 2000 (as presented in Tables 3-5, 3-6, and 3-7) was due to installation of new equipment, this increase could be converted to equivalent required generating capacity to satisfy the demands of additional electrical equipment. This generating capacity was added to the projection of Case I to determine the Case II projection of required generating capacity of 1972 and 1985 and 2000 (as presented in Tables 3-5, 3-6, and 3-7) was due to installation of new equipment, this increase could be converted to equivalent required generating capacity to satisfy the demands of additional electrical equipment. This generating capacity was added to the projection of Case I to determine the Case II projection of required generating capacity of 1985 and 2000 (Table 7-3).

The relative efficiencies of the electric and fossil fuel equipment were included in the conversion to equivalent generating capacity. This calaculation was made separately for each primary end use and then summed for 1985 and 2000. An example calculation for space heat is presented below for the years 1985 and 2000.

The increase in fossil fuel use for residential space heat per year between 1972 and 1985 is 1194×10^{12} Btu (Tables 3-5 and 3-6). Using conversions of 3413 Btu per kwhr and a 64% load factor

$$1194 \times 10^{12} \frac{\text{Btu}}{\text{yr}} \times \frac{\text{kwhr}}{3413 \text{ Btu}} \times \frac{\text{yr}}{8760 \text{ hr}} = 4.1 \times 10^{4} \text{ Mw}$$

$$4.1 \times 10^7 \text{ kw} \times \frac{60\% \text{ fossil fuel efficiency}}{100\% \text{ electric efficiency}} = 2.5 \times 10^4 \text{ Mw}$$

$$\frac{2.5 \times 10^7 \text{ kw}}{.64 \text{ load factor}} = 3.9 \times 10^7 \text{ kw}$$

of generating capacity are required to meet the demand due to increased residential electric space heating in 1985.

Between 1972 and 2000, the increase is 3083 x 10^{12} Btu. Using conversions of 3413 Btu per kwhr and a 66% load factor

$$3083 \times 10^{12} \frac{\text{Btu}}{\text{yr}} \times \frac{\text{kwhr}}{3413 \text{ Btu}} \times \frac{\text{yr}}{8760 \text{ hr}} = 1.1 \times 10^5 \text{ Mw}$$

$$1.1 \times 10^8 \text{ kw} \times \frac{60\% \text{ fossil fuel efficiency}}{100\% \text{ electric efficiency}} = 6.3 \times 10^4 \text{ Mw}$$

$$\frac{6.3 \times 10^7 \text{ kw}}{.66 \text{ load factor}} = 9.5 \times 10^4 \text{ Mw}$$

of generating capacity are required to meet the demand due to increased residential electrical space heating in 2000.

The installed electric generating capacity required to satisfy the assumptions made for Case II was determined by summing the increased generating capacities required for 1985 and for 2000 and adding this to the Case I projections for 1985 and 2000 respectively. Using this method the required generating capacity production for 1985 was 900 x 10^3 Mw and the projection for 2000 was 1800 x 10^3 Mw.

7.2.1.3 Case III Requirements

Two separate approaches were necessary to project 1985 and 2000 required generating capacity for Case III. By the year 2000 all equipment would be electric so the projection for that year was simply a conversion of the total primary fossil fuel usage for the year 2000 (Table 3-7) to generating capacity. As in Case II, the relative efficiencies of the types of equipment were considered but no peak margin for the new capacity was added.

Projecting the 1985 generating capacity was more difficult as not all of the fossil fuel equipment would have been retired and replaced by electrical equipment by 1985. Therefore, additional generating capacity to meet only the demands of the retired fossil fuel equipment were necessary. This additional generating capacity was determined based on the lifetime of the fossil fuel equipment and the historical fossil fuel usage of the primary end uses. Space heat and cooking fossil fuel consumption in 1968 (Table 3-1) and water heating fossil fuel consumption in 1972 (Table 3-5) were converted to equivalent generating capacity using the same methods as for 2000. Assuming finite lifetimes of 15, 17, and 12 years for space heat, cooking, and water heating respectively, fossil fuel consumption that would be replaced by electrical energy by 1985 was estimated using available data for the years 1968 and 1972.

For 1985 the projected required generating capacity was 1300 x 10^3 Mw and for 2000 it was 2300 x 10^3 Mw.

7.2.2 Factors Influencing Capacity Expansion

Some factors in addition to demand that might be considered in projections of the maximum rate of power plant expansion are discussed below.

7.2.2.1 Availability of Capital

The electric utility industry is the most capital intensive industry in the United States. About 12% of the total U. S. investments each year are channeled to the power industry. An annual rate of expenditure of over $30 billion, more than triple the $10 billion invested in 1970, has been estimated as the capital requirement for the utility industry between the present and 1985 (NA-174, TI-026).

7.2.2.2 Availability of Water

Thermal power plants require substantial amounts of water for cooling purposes. The principle effect of this water use is the evaporation of about five pounds of water for each kwhr of electricity produced (NA-174). As a result, the availability of water is a major factor in the siting of a generating facility (TI-026). Also, the mode of cooling is of prime importance as it directly affects fuel cycle efficiency to produce electrical power (ST-198).

There has been increasing concern over water use, particularly in certain areas of the United States. Typical of this concern is recently enacted legislation by the state of Montana imposing a three-year moratorium on water allocations from the Yellowstone River basin (NA-174). Substantial portions of the nations coal reserves are located west of the Mississippi River, where a relative scarcity of water exists and about 90% of the existing available water is used for agriculture.

7.2.2.3 Availability of Fuel

Fuel availability is an extremely complex and crucial factor affecting expansion of the utility industry. Utilities have opted for various fuels to fire new units depending on government policy, environmental requirements, fuel supply, and economic factors (NA-174). Presently, the power industry is in a state of uncertainty as far as which fuel should be used for future plants. Potential constraints are associated with each type of fuel so that no clear solution is apparent. The natural gas and fuel oil supply is very uncertain, and coal fired and nuclear plants are encumbered with environmental problems.

Lack of transportation facilities could affect the availability of fuels to the power industry. Important shifts in regional transportation requirements might result from the development of Alaskan oil and gas and Western coal. The greatest potential problem is probably the railroads (the primary coal carrier) as they have encountered financial difficulties leading to reduced hauling capacity (FE-076).

7.2.2.4 Environmental Impacts

As long as natural gas and low sulfur fuel oil supplies were plentiful, environmental concerns were not considered a critical factor in the expansion of the utility industry. However, as a major portion of future expansion and new construction will probably involve coal-burning units, the environmental impacts of generating stations will become a primary factor in determining the rate of expansion of generating capacity. Likewise, the development of raw energy resources necessary for utility expansion might be slowed down by environmental considerations (TI-026).

7.2.2.5 Lead Time Requirements

Very sizeable lead times are required to bring new plants on line. Typical new plant lead times (go-ahead to beneficial operation) experienced in 1973 are shown in Table 7-1 below.

TABLE 7-1

TYPICAL 1973 OVERALL PROJECT TIMES
(from go-ahead to production)

Type of Facility	Years
Coal-fired power plant	5-8
Surface coal mine	2-4
Underground coal mine	3-5
Uranium exploration and mine	7-10
Nuclear power plant	9-10
Hydroelectric dam	5-8
Produce oil and gas from new fields	3-10
Produce oil and gas from old fields	1-3

Source: (NA-174)

Current lead times for other types of energy facilities are given below.

TABLE 7-2

Estimated Facility Lead Times
(years from decision to start-up)

Type of Facility	Years Lead Time
Geothermal Electric Plants	5
Oil Electric Plants	5
Synthetic Fuel Plants	
Low Btu Gas	5
Pipeline Gas	5
Liquefaction	5
Shale Oil Plants	6

Source: (FE-095)

7.3 Projection Results

The production rates of end use equipment for the years 1960 to 1974 indicate a 200% increase in production rates for electrical space heating and water heating equipment and a 100% increase for electrical cooking equipment relative to 1960 production figures for each. The increase in installed electric generating capacity was about 100% for the same time period. The following results consider increases in production or generating capacity relative to 1974 figures.

Based on Case I assumptions, the equipment manufacturers would have to increase production about 10% by 1985 for each end use and about 60% for space heating, 80% for water heating, and 30% for cooking by 2000. The utility industry would have to increase its installed generating capacity about 80% by 1985 and about 270% by 2000 (Table 7-3).

TABLE 7-3

INCREASES IN ELECTRIC EQUIPMENT PRODUCTION AND UTILITY GENERATING CAPACITY (RELATIVE TO 1974 FIGURES)

	EQUIPMENT MANUFACTURE			UTILITY GENERATING CAPACITY
	SPACE HEATING	WATER HEATING	COOKING	
1985				
CASE I	10%	10%	10%	80%
CASE II	120%	60%	20%	110%
CASE III	400%	170%	90%	220%
2000				
CASE I	60%	80%	30%	270%
CASE II	260%	140%	50%	330%
CASE III	480%	220%	140%	450%

Using Case II criteria, production rates would increase 120% for space heating, 60% for water heating, and 20% for cooking by 1985. The corresponding increase of installed generating capacity is 110%. By the year 2000 production rates for space heating would increase 260%, for water heating 140%, and for cooking 50% along with a 330% jump in electric generating capacity.

For Case III, a 400% increase in space heater production rates, a 170% increase for water heating, and a 90% increase for cooking would be required by the year 1985. The utility industry as a result would have to expand generating capacity by 220% by 1985. By the year 2000, the manufacturing rates would increase by 480% for space heaters, 220% for water heaters, 140% for cooking equipment, and the generating capacity would have to increase 450%.

Assuming that the equipment manufacturers and utility industry attain rates of increase in production and capacity equal to their historical growth previously discussed, an overall rate of application of electrical equipment falling between the Case I and Case II projections might be feasible. Some equipment such as cooking and water heating might even attain a Case III rate of application.

The most serious constraint on the rate of application of electrical equipment is probably the rate at which utilities can expand and construct new facilities. Practicable solutions to the problems faced by the power industry such as capital, water and fuel availability, and the environment must be found if utilities are to grow even at the Case I projected rate. A significant influence would probably have to be exercised over the utility industry for the electric demand resulting from Case II guidelines to be met. Also, some influence might have to be exercised over the electrical space heating manufacturers to enable this industry to meet the requirements resulting from a Case II replacement rate.

The electricity demand in the years 1985 and 2000 was estimated in Section 3.0. This demand is converted to 10^3 Mw of generating capacity using 3413 Btu per kwhr and a 64% and 66% load factor in 1985 and 2000 respectively. The estimated installed generating capacity in 1985 is about 740 x 10^3 Mw and in 2000 about 1500 x 10^3 Mw. Based on the projections of Table 7-3, the installed generating capacity in those years may exceed this projected demand thus providing electrical energy to fill "gaps" in clean fuel availability which may exist in the future.

8.0 DEFINITION OF EQUIPMENT COSTS

This section presents an economic comparison of fossil-fuel fired equipment and electrical equipment used in the residential, commercial, and industrial sectors. The residential and commercial sectors are discussed in considerable detail since a high percentage of the total fossil-fuel energy utilized in these sectors may be switched to electricity (100 and 83% respectively). Less emphasis is given to the industrial sector since only 9% of the fossil fuel energy used in that sector is switchable. Capital and operating costs for both 1972 and 1974 are presented. 1972 is the base year used throughout this study. 1974 cost data are presented so that recent trends in fuel costs and electric and fossil-fuel fired equipment costs may be considered.

Cost comparisons were made for items in each of the sectors that are used in processes where either fossil fuels or electricity may be used to supply the energy. In the residential sector, these processes include space heating, water heating, air conditioning, clothes drying, and cooking. Refrigeration is not included because gas powered refrigerators are no longer manufactured. In the commercial sector the processes considered are space heating, water heating, cooking, and air conditioning. The equipment considered in the industrial sector is classified by industry type. The industries discussed include steel making, aluminum processing, glass production, chemical industries, and food processing. The processes considered are melting, heating and annealing, cooking, and space heating.

8.1 Residential Sector Equipment

The energy end uses in the residential sector which may be switched from fossil-fuel fired equipment to electrically operated equipment are space heating, water heating, air conditioning, clothes drying, and cooking. The discussion of capital and operating costs for this equipment is divided into three sections. First the bases and assumptions used in determining the capital and operating costs for the various equipment types used in the residential sector are discussed. This includes natural gas, oil, and electric rates, and methods and assumptions used to estimate capital and operating costs where direct information was not available.

The 1974 capital and operating costs for residential equipment are presented in the second section along with the capital and operating costs for 1972. Costs are presented for both 1972 and 1974 to show recent trends in capital and operating costs for the various types of residential equipment. These costs are discussed in a comparative manner so that the economic advantages and disadvantages of both electric and fossil-fuel powered equipment may be considered.

The third section contains a present cost analysis for several of the residential sector equipment types. In some cases a comparison of present day capital and operating costs does not clearly indicate which alternative is least expensive over the life of the equipment. This situation arises when alternative X has a higher capital cost than alternative Y, but alternative Y has a higher operating cost. This situation may also occur if the price of one energy source is rising faster than the price of another, as is the case of natural gas and electricity (the price of natural gas is rising faster than the price of electricity). A present cost analysis is presented to give a more accurate picture of the relative costs of fossil fuel and electric equipment. The detailed cost calculations may be found in Appendix E.

8.1.1 Bases for Equipment Cost Calculations - Residential Sector

The capital costs for residential equipment for 1974 were estimated by obtaining the total number of units shipped and the installed value of the units (TE-177, EN-221). The 1974 capital cost for each item is then given by:

$$\text{Capital Cost} = \frac{\text{Installed Value of 1974 Shipments}}{\text{Number of Units Shipped}}$$

This type of information was available for all items except gas air conditioners. A 1974 capital cost estimate for this item was obtained from the American Gas Association (AM-126).

The capital costs for 1972 were obtained in the same manner as the 1974 capital costs except for space heaters and air conditioners. The 1972 capital costs for these two items were obtained in the following manner:

$$\text{1972 Capital Cost} = \text{1974 Capital Cost} \times R$$

where R is the average 1972/1974 capital cost ratio for the type of equipment considered (electric, oil, or natural gas). The value of R for electric equipment is 0.935 and the value for fossil fuel equipment is 0.928.

The operating costs for each type of residential equipment previously identified depend upon the amount of energy consumed by each piece of equipment and the cost of that energy (electricity, oil, or natural gas). The 1972 and 1974 national average electric, oil, and natural gas rates (AM-124, AM-125, FE-090, RE-123, RE-124) used in calculating the operating costs for residential equipment are shown in Table 8-1.

TABLE 8-1

RESIDENTIAL ENERGY COSTS ($/$10^6$ BTU)

	1972	1974
Electricity	7.03	8.26
Natural Gas	1.19	1.42
No. 2 Fuel Oil	0.71	1.84

The average yearly energy consumption for each type of residential electric equipment except space heaters is shown in Table 8-2.

TABLE 8-2

AVERAGE YEARLY ENERGY CONSUMPTION FOR ELECTRICAL EQUIPMENT

Equipment Type	10^6 BTU/YR	SOURCE
Clothes Dryer	3.39	HO-176
Microwave Oven	0.65	HO-176
Electric Oven	4.0	HO-176
Water Heater	14.4	HO-176
Air Conditioner, room	4.74	AI-018
Air Conditioner, Central (assume 5 rooms)	23.7	

The average space heating energy requirement for gas heating is 119 x 10^6 Btu/yr (AM-126). The energy required for an electric space heater may be calculated as follows. Assuming efficiencies for the fossil-fuel and electric heaters of 60% and 100% respectively (See Appendix B), the electric space heater energy requirements is:

$$119 \times 10^6 \text{ Btu/yr} \times \frac{60\%}{100\%} = 71 \times 10^6 \text{ Btu/yr}$$

The average annual energy requirement for the residential gas powered equipment was calculated based on equipment efficiencies as defined in Appendix B. The relative efficiencies used in calculating the energy requirements for the gas fired equipment are shown in Table 8-3.

TABLE 8-3

ENERGY USE EFFICIENCIES FOR FOSSIL-FUEL AND ELECTRIC RESIDENTIAL EQUIPMENT

	Efficiency	
Equipment Type	Fossil-Fuel	Electric
Clothes Dryer	49%	55%
Oven	37%	75% (82%)*
Water Heater	60%	92%
Air Conditioning	30%	50%
Space Heater	60%	95%

---

* Microwave Oven

The gas powered equipment energy requirements were calculated using these efficiencies as follows:

$$E_G = E_E \times \eta_E / \eta_G$$

where:

E_G = gas-powered equipment energy requirement

E_E = electric equipment energy requirement

η_E = efficiency of electric equipment
η_G = efficiency of gas-powered equipment

Once the energy required for each piece of equipment and the cost for that energy is known, the yearly operating costs for each item may be calculated as follows:

$$\text{Operating Cost} = (\text{Energy Requirement}) \times (\text{Cost per Energy Unit})$$

In the case of air conditioners, however, the capital costs obtained were for central units, whereas the energy requirements were for window units. It was assumed that one central unit is equivalent to five rooms cooled by window units so that the total energy requirement for a central air conditioning system is five times that shown in Table 7-1 for a room air conditioner.

8.1.2 Capital and Operating Costs of Residential End Use Equipment

The capital and operating costs for residential equipment which may be either electric or fossil-fuel powered (air conditioner, space heater, stove/oven, clothes dryer, and water heater) were calculated using the assumptions and methodologies described in the previous section. Table 8-4 presents a summary of the capital and operating costs for residential equipment for 1972 and 1974. A comparison of the capital costs for electric equipment to the capital costs for natural gas powered equipment for 1972 shows that electric air conditioners and clothes dryers are less expensive than natural gas powered air conditioners and dryers (38% and 14%, respectively). However, natural gas powered space heaters,

TABLE 8-4

CAPITAL AND OPERATING COSTS FOR ELECTRIC AND GAS POWERED RESIDENTIAL EQUIPMENT

1972 Costs

	Electric		Natural Gas		Oil	
Equipment Type	Capital Cost, $	Operating Cost, $/yr	Capital Cost, $	Operating Cost, $/yr	Capital Cost, $	Operating Cost, $/yr
Air Conditioner, Central	857	167	1,390	47	-	-
Space Heater	502	503	477	141	526	86.9
Stove/oven	219 (400)*	28 (4.6)*	212	9.6	-	-
Clothes Dryer	169	24	196	4.6	-	-
Water Heater	90	101	85	26	-	-

1974 Costs

	Electric		Natural Gas		Oil	
Equipment Type	Capital Cost, $	Operating Cost, $/yr	Capital Cost, $	Operating Cost, $/yr	Capital Cost, $	Operating Cost, $/yr
Air Conditioner, Central	917	196	1,500	56	-	-
Space Heater	541	591	514	169	567	225
Stove/oven	240 (367)*	33 (5.4)*	229	12	-	-
Clothes Dryer	181	28	210	5.5	-	-
Water Heater	97	119	92	31	-	-

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*Microwave Oven

stove/ovens, and water heaters are less expensive than their electric counterparts by 6%, 3%, and 6%, respectively. The oil-fired space heater is 5% more expensive than the electric space heater and 10% more expensive than the gas-fired heater. Also, the gas stove/oven is 41% cheaper than the microwave oven.

A comparison of the operating costs of electric and natural gas equipment shows a quite different cost profile than the comparison of capital costs. The only electric equipment which is less expensive than its gas counterpart on an operating cost basis is the microwave oven. The average annual operating cost for a microwave oven is 52% less than that of a gas stove/oven (\$4.6/yr versus \$9.6/yr). All of the other electric equipment operating costs are greater than their fossil fuel equivalents' costs. Gas powered air conditioners and space heaters are both 72% less expensive to operate. A gas stove/oven is 65% less, a dryer is 81% less, and a water heater is 74% less expensive to run than their electric substitutes. This is because electricity is a more expensive energy source than natural gas (\$7.03/10^6 Btu versus \$1.19/10^6 Btu, based on 1972 prices). However, as natural gas becomes more difficult to obtain, the price of natural gas probably will rise much faster than that of electricity, and may make electric equipment more attractive.

The operating cost of a microwave oven is less than that of a gas stove/oven but the capital cost is greater. However, from 1972 to 1974 the capital cost of a microwave oven dropped from \$400 to \$367. Continued decreases in microwave oven capital costs coupled with increasing natural gas prices may make electric cooking with microwave ovens more attractive.

8.1.3 Present Cost Analyses of Residential End Use Equipment Options

Capital and operating costs for each of the five types of residential equipment were presented above. Of these five types of equipment, three (microwave ovens, gas air conditioners, and gas clothes dryers) have higher initial costs and lower operating costs than their substitutes. In order to more adequately define the cost differentials between these types of electric and fossil-fuel powered equipment, a present cost analysis is presented in this section. Table 8-5 summarizes the results of the present cost calculations. The details may be found in Appendix E.

Three cases were considered. In Case 1, natural gas and electricity prices were assumed to remain constant and an interest rate of 8% was used. In Case 2 it was assumed that natural gas and electricity costs increased at the same rate as they have from 1972 to 1974 (9.87% and 8.75%, respectively) and that the interest rate was 8%. Case 3 has the same assumptions as Case 2 except that the interest rate was assumed to be 12%. For all three of these cases an equipment life of 20 years was assumed.

The present cost calculations for cooking equipment (see Table 8-5) show that for 1972, in all cases the gas stove/oven is the least expensive and the electric stove/oven is the most costly, with the microwave oven intermediate. For Case 2, the microwave oven is 45% more expensive than the gas stove/oven. Case 2 shows that it is 16% more expensive and Case 3 shows the microwave oven to be 30% more expensive than a gas stove/oven. For the 1974 calculations, Case 1 and Case 3 show the microwave oven to be more expensive than a gas stove/oven (23% and 10% respectively). However, Case 2 shows that the microwave oven is cheaper than a gas stove/oven by 1.7%. The lowering of the capital cost of the microwave oven from $400

TABLE 8-5

PRESENT COST ANALYSIS FOR VARIOUS RESIDENTIAL EQUIPMENT

Equipment Type	Present Cost, $					
	1972			1974		
	Case 1 (1)	Case 2 (2)	Case 3 (3)	Case 1 (1)	Case 2 (2)	Case 3 (3)
Stove/oven, electric	496	777	673	565	896	694
Microwave oven	445	490	462	420	473	441
Stove/oven, gas	307	423	356	342	481	402
Dryer, electric	403	641	495	456	735	565
Dryer, gas	241	297	265	264	330	292
Air conditioner, electric	2,497	4,162	3,145	2,841	4,796	3,602
Air conditioner, gas	1,851	2,419	2,094	2,050	2,726	2,338

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(1) Case 1: Based on equipment lifetime of 20 years, interest rate of 8% per year., and constant electricity and natural gas prices.

(2) Case 2: Based on equipment lifetime of 20 yr., interest rate of 8% per yr., cost of electricity increases 8.75% per yr., and natural gas cost increases at a rate of 9.87% per yr. (1972-1974 average increases).

(3) Case 3: Same assumptions as Case 1 except the interest rate is 12% per yr.

in 1972 to $367 in 1974 resulted in a decrease in cost differential between the microwave oven and the gas stove/oven.

The present cost calculations for clothes dryers and air conditioners show that the higher operating costs for the electric items are more than enough to offset the higher capital costs for the gas powered equipment, making the electric equipment more expensive in all cases.

8.2 Commercial Sector

The major energy end uses in the commercial sector which may be switched from fossil-fuel powered equipment to electric equipment are space heating, water heating, cooking, and air conditioning. The following discussion of capital and operating costs for commercial equipment consists of a description of the bases and assumptions used to determine the costs and a presentation and discussion of the results of the cost calculations.

8.2.1 Bases for Equipment Cost Calculations - Commercial Sector

This section contains a discussion of the assumptions and methodologies used to obtain cost estimates for the commercial equipment identified above. The fuel costs used for the estimations are shown below in Table 8-6.

TABLE 8-6

COMMERCIAL ENERGY COSTS ($\$/10^6$ BTU)

	1972	1974
Electricity	9.96	11.4
Natural Gas	0.91	1.10
No. 2 Fuel Oil	0.71	1.84

Since no average energy requirements for commercial equipment were found, the operating costs were defined on a usable energy output basis as follows:

$$\text{Cost } (\$/\text{Btu}) = \frac{1}{\eta} \times P$$

where:

η = equipment efficiency

P cost of fuel, $\$/10^6$ Btu

The operating cost for a microwave oven was calculated on an equivalent energy basis as follows:

$$\text{Cost}_M \ (\$/\text{Btu}) = \text{Cost}_E \times \frac{E_M}{E_E}$$

where:

Cost_M = operating cost for a microwave oven

Cost_E = operating cost for an electric stove/oven = $1/\eta$

E_M = average annual energy requirement for a residential microwave oven

E_E = average annual energy requirement for a residential electric stove/oven

The ratio of the microwave oven energy requirement to the electric stove/oven energy requirement for commercial equipment was assumed to be the same as that for residential equipment.

Capital costs for commercial equipment were not readily available except for stove/ovens. The 1974 capital costs of electric and gas commercial ranges (EN-221) were obtained as follows:

$$\text{Capital Cost} = \frac{\text{Retail Value of Commercial Shipments}}{\text{Number of Units Shipped}}$$

No capital cost data were found for the other commercial items. The detailed calculations for the commercial capital and operating costs are presented in Appendix E.

8.2.2 Capital and Operating Costs of Commercial End Use Equipment

As previously mentioned, the only capital cost data found for commercial equipment were for gas and electric ranges. These values were \$609 and \$637, respectively. The ratio of electric to gas capital costs for ranges is approximately the same as the residential ratio. This is probably true for the other commercial equipment also, since the commercial items are essentially the same as residential equipment with larger capacities. Assuming that the capital costs of these types of equipment follow the logarithmic relationship known as the "six-tenths factor",

$$C_c = C_r(r)^{0.6}$$

where:

C_c = commercial equipment cost

C_r = residential equipment cost

r = capacity ratio of commercial equipment to residential equipment

the electric to gas equipment cost ratio can be written as

$$R_c = \frac{C_{c,e}}{C_{c,g}} = \frac{C_{r,e}(r)^{0.6}}{C_{r,g}(r)^{0.6}} = \frac{C_{r,e}}{C_{r,g}} = R_r \quad .$$

where:

R_c = electric to gas ratio for commercial equipment

$C_{c,e}$ = cost of commercial electric equipment

$C_{c,g}$ = cost of commercial gas equipment

$C_{r,e}$ = cost of residential electric equipment

$C_{r,g}$ = cost of residential gas equipment

R_r = electric to gas ratio for residential equipment

If this relationship is true for the commercial equipment, then the same conclusions made in the residential sector discussion concerning relative capital costs for each of the types of equipment may be made for the commercial sector. On this basis, electric space heaters and water heaters are probably about five to six percent more expensive than their gas powered counterparts.

The operating costs for commercial equipment which may be either fossil fuel or electric powered are shown in Table 8-7 on a usable energy basis. As in the residential sector, the only electrical equipment that has a lower operating cost than gas powered equipment is the microwave oven. This is because electricity is considerably more expensive than natural gas on a common energy basis (cost/Btu). The difference in efficiencies of electric and gas equipment (electric is in general more efficient) is not significant enough to make up for the fuel cost differentials. However, as natural gas becomes more difficult to obtain and prices rise, electrical equipment in the commercial sector may become more attractive.

8.3 Industrial Sector

Section 4.0 and Appendix B present a detailed breakdown of the fossil-fuel energy end uses in the industrial sector which could be satisfied by electrical equipment in 1968. The end uses that were identified are space heaters, steel making furnaces, equipment for heating and annealing of steel, aluminum melting furnaces, glass melting furnaces, and cooking equipment used in the food processing industry. This section presents a discussion of the assumptions and methodologies used to calculate the industrial sector costs and the results of the cost calculations. A comparative discussion of the various alternatives is also included in this section. The detailed calculations for the industrial sector are presented in Appendix B.

TABLE 8-7

COMMERCIAL OPERATING COSTS

Equipment Type	1972			1974		
	Oil Operating Costs, $\$/10^6$ Btu	Gas Operating Costs, $\$/10^6$ Btu	Electric Operating Costs, $\$/10^6$ Btu	Oil Operating Costs, $\$/10^6$ Btu	Gas Operating Costs, $\$/10^6$ Btu	Electric Operating Costs, $\$/10^6$ Btu
Space Heater	0.96	1.18	10.45	2.48	1.44	12.0
Water Heater	-	1.51	10.80	-	1.84	12.39
Cooking	-	2.45	13.25 (2.14)*	-	2.99	15.20 (2.46)*
Air Conditioning	-	3.02	19.87	-	3.68	22.80

*Microwave oven

8.3.1 Bases for Equipment Cost Calculations - Industrial Sector

No values for capital costs were found for the industrial sector equipment. However, a relative description of the cost advantages and disadvantages of electric furnaces as compared to fossil-fuel fired furnaces is given below.

Operating costs may be estimated using the energy requirements for each process along with the energy costs. The energy requirements for each of the previously mentioned industrial processes were presented in Section 4.0 and Appendix B. These requirements are shown in Table 8-8. The energy requirements for space heating and cooking were calculated on a usable energy basis as follows:

$$\text{Energy Required/Usable Btu} = \frac{1}{\eta}$$

where:

η = equipment efficiency

Average fuel costs for natural gas, electricity, distillate oil (No. 2) and residual oil (low sulfur) were obtained for 1972 and 1974 (AM-124, AM-125, FE-090, RE-123, RE-124) and are shown in Table 8-9. Once the energy requirements and the energy costs are known, the operating costs may be calculated as follows:

$$\text{Operating Cost} = R_E \times C_E$$

TABLE 8-8

ENERGY REQUIREMENTS FOR INDUSTRIAL SECTOR PROCESSES

Process	Energy Requirements (Btu/ton)	
	Electric	Fossil Fuel
Steel-making	1.9×10^6	4.3×10^6
Heating and Annealing of Steel	2.1×10^6	19.0×10^6
Aluminum Melting	2.1×10^6	4.7×10^6
Glass Melting	2.9×10^6	16.0×10^6

TABLE 8-9

AVERAGE INDUSTRIAL FUEL COSTS ($/$10^6$ BTU)

Fuel Type	1972	1974	Source
Electricity	6.74	8.26	FE-090
Natural gas	.45	.66	AM-124, AM-125
No. 2 fuel oil	0.71	1.84	RE-123, RE-124
Low sulfur resid	0.61	1.96	RE-123, RE-124

where:

R_E = energy requirements

C_E = energy costs

8.3.2 Capital and Operating Costs of Industrial End Use Equipment

Although no actual capital cost figures for the industrial equipment discussed previously were found, the capital costs for electric furnaces are generally higher than the costs for open hearth or other types. This is mainly due to the higher costs of auxiliary equipment, electrodes, and refractories (US-187).

Operating costs for the industrial equipment identified above are presented in Table 8-10. The operating costs for electric space heating are higher for both 1972 and 1974 although the gas and oil operating costs are rising faster than the electric heating costs.

For steel making furnaces, aluminum and glass melting, and heating and annealing of steel, the gas fired equipment operating costs are less than those of the electric and oil fired equipment. For 1972, the oil fired equipment operating costs are in general between the gas and electric costs, but in 1974, the oil fired equipment costs are higher than both of the other types for heating and annealing, and glass melting. This is because the cost of oil increased much faster than that of gas or electricity between 1972 and 1974. The continued increase in oil costs will tend to make oil fired equipment less attractive. Also, as natural gas prices increase because of lack of availability, electrical equipment may become more competitive with natural gas fired equipment.

TABLE 8-10

INDUSTRIAL OPERATING COSTS

Process Type	1972 Operating Costs			1974 Operating Costs		
	Gas	Electric	Oil[1]	Gas	Electric	Oil[1]
Space Heating, $\$/10^6$ Btu	0.58	7.09	0.96	0.85	8.65	2.48
Steel Making						
Furnaces, $/ton	1.93	12.80	2.52	2.82	15.64	8.05
Heating, Annealing, $/ton	8.53	14.15	11.15	12.48	17.29	35.60
Aluminum Melting, $/ton	2.11	14.15	2.76	3.09	17.29	8.81
Glass Melting, $/ton	7.18	19.54	9.39	10.51	23.87	29.98
Food Industry						
Cooking, $\$/10^6$ Btu	1.21	8.99	0.77	1.77	10.98	2.46

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[1] No. 2 Fuel Oil for space heating, low sulfur residual oil for all other processes.

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